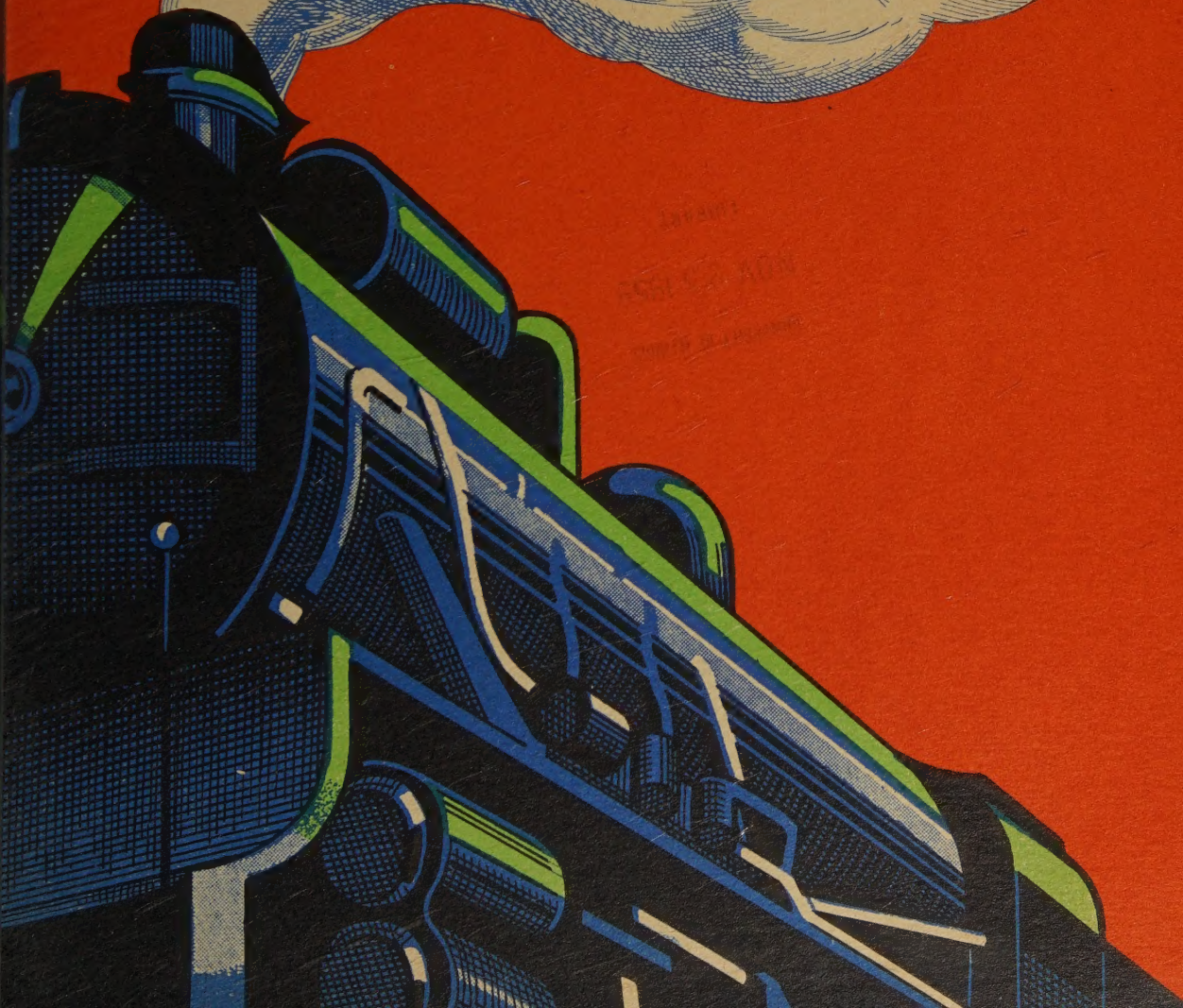
VOL. XXXVI. — No. 10. OCTOBER 1959.

# Monthly Bulletin of the International Railway Congress Association

(English Edition)



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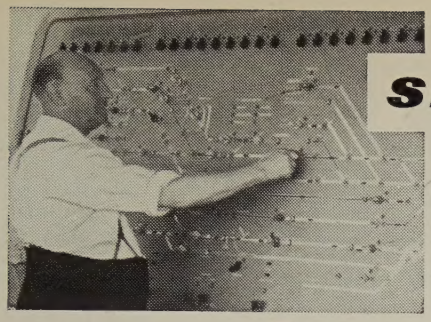

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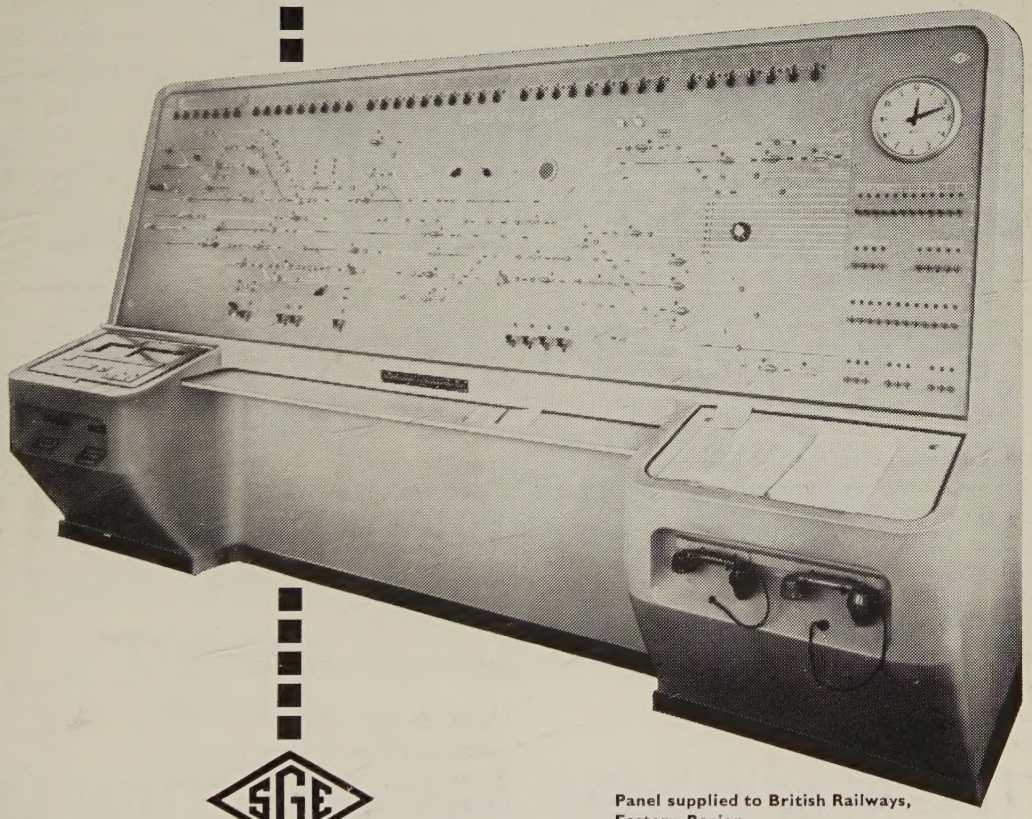

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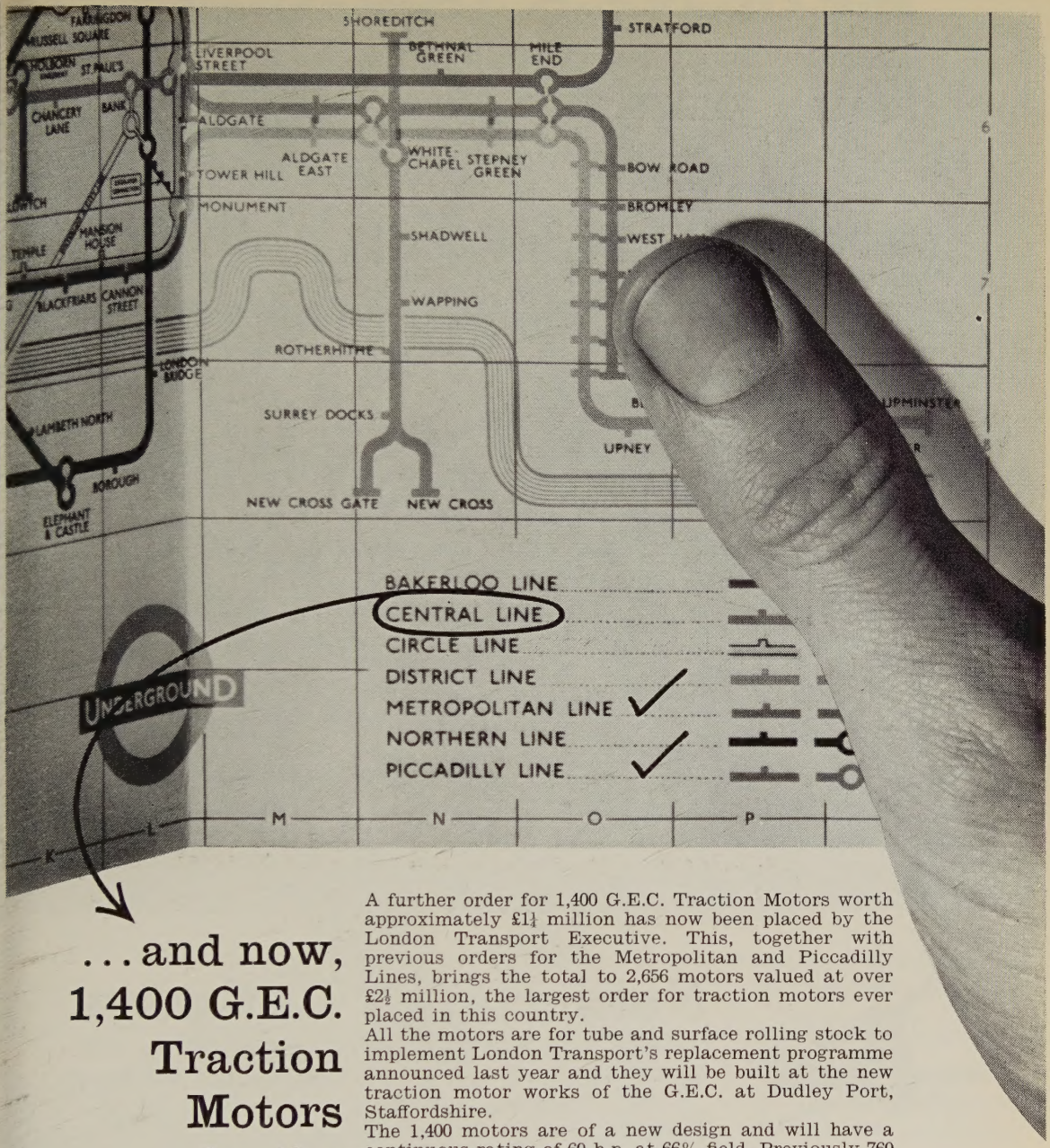


# ...and now, 1,400 G.E.C. Traction Motors for the Central Line

A further order for 1,400 G.E.C. Traction Motors worth approximately £1¼ million has now been placed by the London Transport Executive. This, together with previous orders for the Metropolitan and Piccadilly Lines, brings the total to 2,656 motors valued at over £2½ million, the largest order for traction motors ever placed in this country.

All the motors are for tube and surface rolling stock to implement London Transport's replacement programme announced last year and they will be built at the new traction motor works of the G.E.C. at Dudley Port, Staffordshire.

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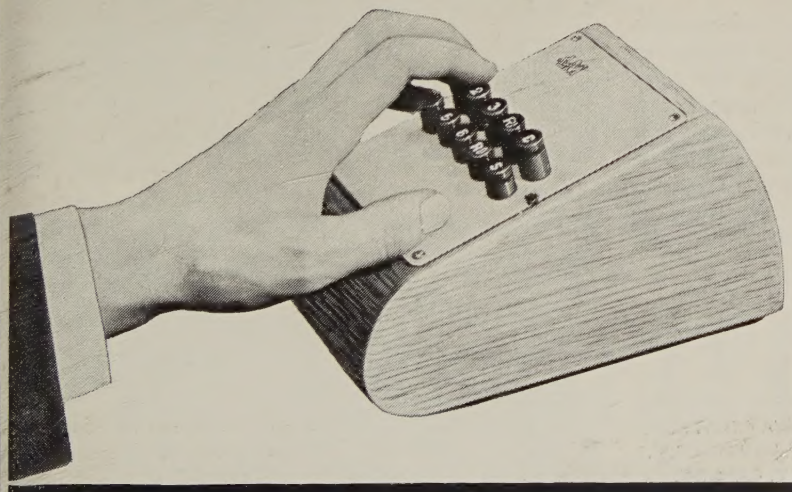

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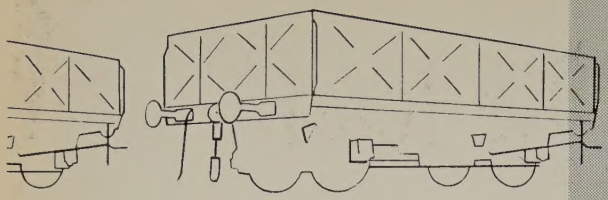
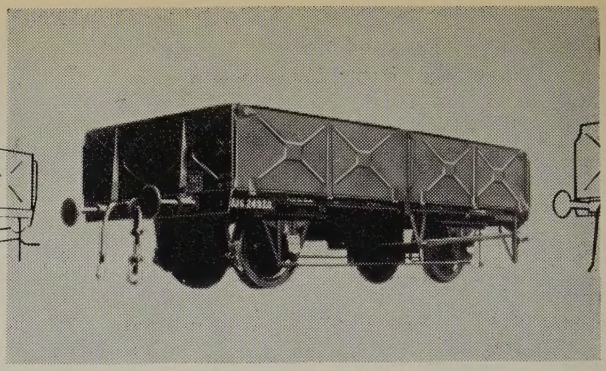
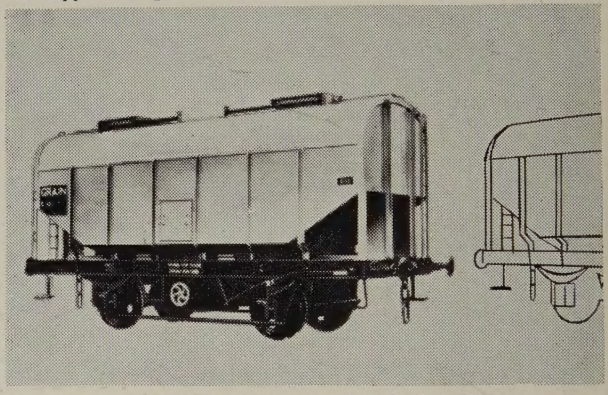




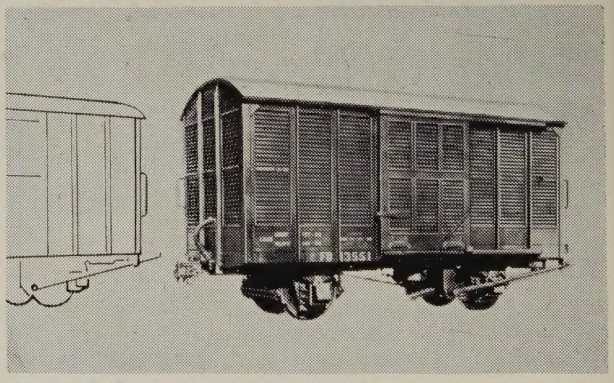
The F.J.S. Low-sided Wagon,
as supplied to Queensland Government Railways, Australia.

# A capacity of 1,400,000 tons



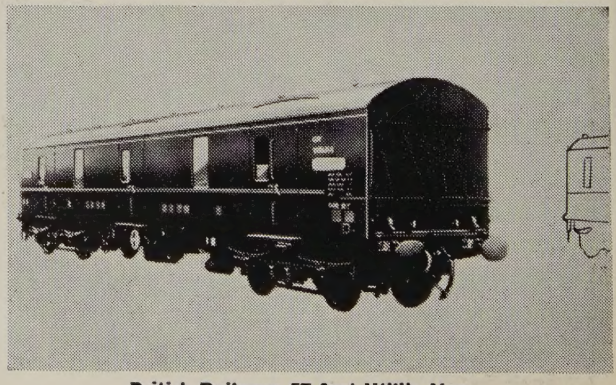
The 20-ton Bulk Grain Van, used by British Railways.

THE CARRYING CAPACITY of the rolling stock produced by Pressed Steel in the past eight years adds up to 1,400,000 tons. This figure is made up of carriages and wagons of all types, for all gauges, at home and overseas. You see some of this rolling stock here.



The F.D. Louvre Van, used by Western Australian Railways.

The figures prove that Pressed Steel have tremendous productivity—and a rich store of engineering experience. But they tell only part of the story. For they do not show the progressive approach of our design staff, the quality of engineering that goes into each job, and our record for prompt delivery. Nor do they show how constant, intensive research has made Pressed Steel ready to play an active part in the future development of the world's carriages and wagons.



British Railways 57-foot Utility Van.

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**Now 'ENGLISH ELECTRIC' equip the first 25 kV A.C. multiple unit trains built by British Railways.**

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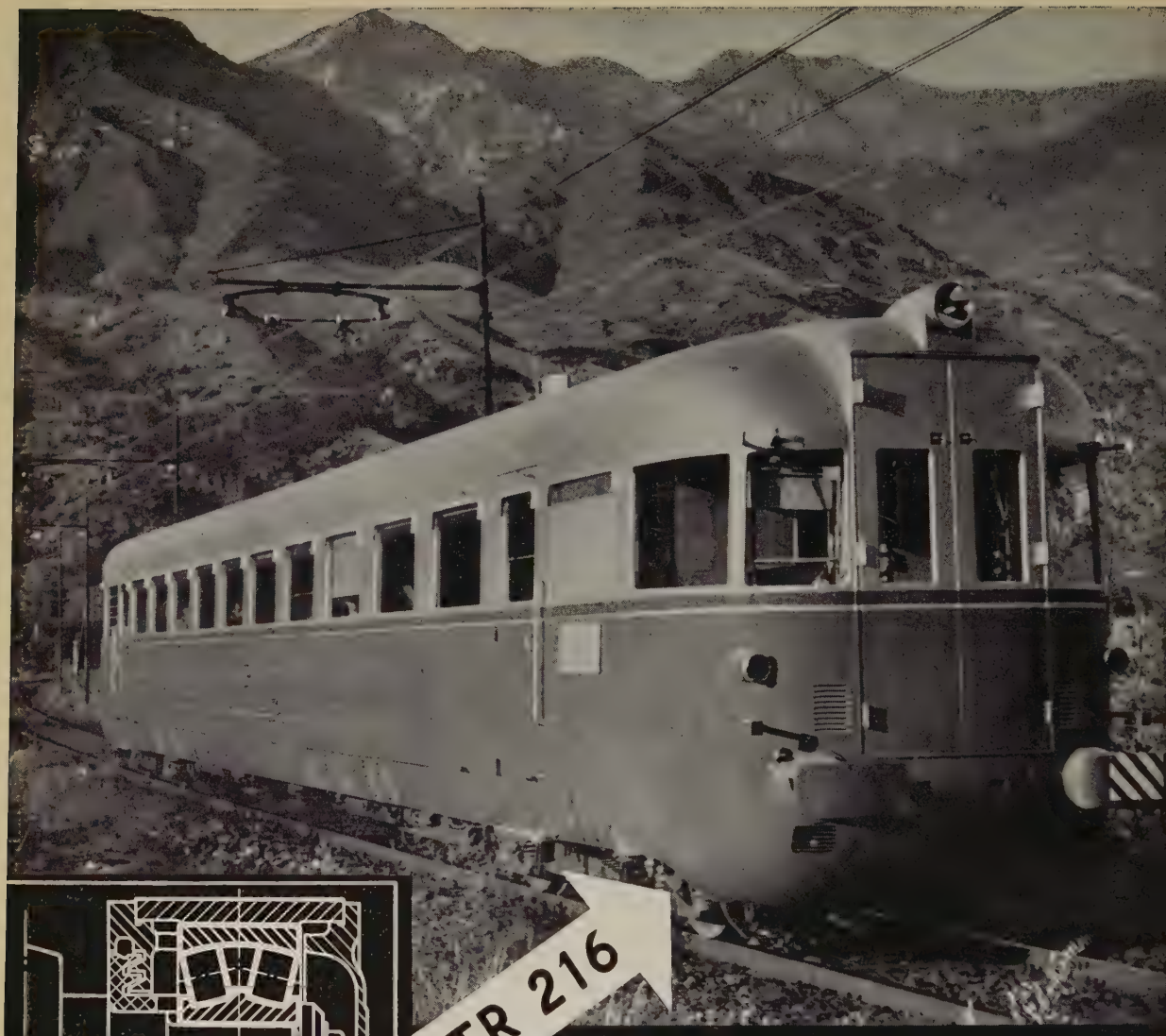

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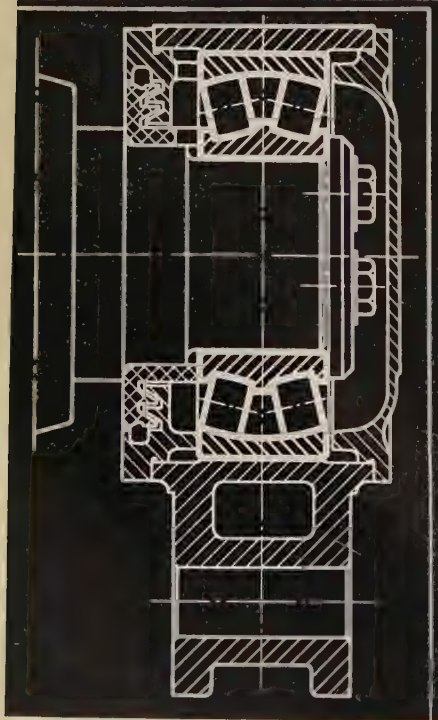
FIAT 077B RAILCAR IN OPERATION ON GREEK RAILWAYS



# RAILWAY JOURNAL AXLE-BOXES

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# Marelli

COMPLETE ELECTRICAL EQUIPMENT FOR D. C., A. C.
DIESEL-ELECTRIC LOCOMOTIVES
AND FOR METROPOLITAN RAILWAYS

DIESEL-ELECTRIC locomotive built by MARELLI-NUOVE REGGIANE for the South-East Railways S. P. A. Type Standard « UNIFER B 13 ». — U. I. C. continuous power 825 HP — 13 units are being built.

280 1 350 HP DIESEL-ELECTRIC locomotives, type Co-Co, are being constructed for the Argentine Railways by the ITALIAN and ARGENTINE group G. A. I. A. Projects and design are by E. MARELLI & C., S. P. A. The electric traction equipments are of the same design as above.

**ERCOLE MARELLI & C. - S.p.A. - MILANO**

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*An edition in French is also published.*

Vol. XXXVI. — No. 10. October 1959.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[ 621 .335 ]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

ENLARGED MEETING OF THE PERMANENT COMMISSION
(NEW DELHI, 1959).

QUESTION 2.

# Problems met in the design of multi-current rolling stock. Existing types : experimental results. Future developments.

## REPORT

*(Western Germany, North and South America, South Africa, Australia, Burma, Ceylon, Egypt, Ghana, India, Indonesia, Iran, Irak, Republic of Ireland, Japan, Norway, New-Zealand, Pakistan, Netherlands, Philippines, United Kingdom of Great Britain and Northern Ireland and dependent overseas territories, Sudan, Sweden, and the Union of Socialist Soviet Republics),*

by J. J. Jonker,

Head of the Rolling Stock and Electrical Installations Department of the Netherlands Railways (Utrecht).

### 1. INTRODUCTION.

The mileage of electrically operated railways continues to increase rapidly throughout the world, though the rate of increase may not be the same in the different parts of the world. This is clearly apparent from an examination of Table 1.

It will be seen from Table 2 which, like Table 1, has been reproduced from « Jahrbuch des Eisenbahnwesens », that there is no uniformity as far as the current supply system is concerned. Difficulties may therefore be encountered where networks equipped with different systems link up with each other in the course of further electrification works.

Such difficulties can be overcome in different ways. One of the solutions consists in using polycurrent motor motive power units, a method which assumes more and more importance. That is why the International Railway Congress Association has decided to place on the agenda of the Enlarged Meeting of its Permanent Commission in New Delhi the question of the

TABLE 1. — **Electrified route kilometrage.** (Extracted from « Jahrbuch des Eisenbahnwesens » edition 1955 to 1958).

| | 1955 | 1956 | 1957 | 1958 |
|---|---|---|---|---|
| *Europe* | 35 477 | 37 113 | 40 190 | 44 651 |
| *Africa* | 2 462 | 2 871 | 2 896 | 2 994 |
| *Australia (including New Zealand)* | 660 | 701 | 754 | 850 |
| *Asia* | 17 361 | 15 686 | 18 113 | 16 315 |
| *North- and Central America* | 5 062 | 4 774 | 3 981 | 3 733 |
| *South America* | 2 054 | 2 920 | 2 925 | 2 712 |
| *Total* | 63 076 | 64 065 | 68 859 | 71 255 |

« Problems met in the design of multicurrent rolling stock ».

One reporter was appointed for the administrations corresponding in the French language, and one for those corresponding in English, and a questionnaire was prepared jointly by both reporters in consultation with the Association.

The purpose of this questionnaire was to extract, from the detailed answers received, the factual information as well as the opinions put forward by the different Administrations and to present them as uniformly as possible.

## 2. REVIEW OF THE REPLIES RECEIVED.

The replies received from the associated Administrations corresponding in the English language are compiled in the present report.

A number of Administrations in the countries concerned have not replied; others have merely sent in a very brief reply.

The following Administrations have indicated that they do not possess an electrified railway network :

Burma Railways;
Ceylon Government Railway;
Coras Iompair Eireann;
East African Railways;
Manila Railroad Company (Philippines);
Malayan Railway;
Nora-Bergslags Järnväg (Sweden);
Nyasaland Railways;
Rhodesia Railways;
Tasmanian Government Railways;
Ferrocarriles del Estado (Uruguay);
Deutsche Schlafwagen-Gesellschaft.

Other Administrations have indicated that their rolling stock does not include polycurrent motor motive power units; they are :

Ghana Railway;
Indian Railways;
Indonesian State Railways;
London Transport Executive;
New Zealand Government Raiways;
Nigerian Railway Corporation;
Norges Statsbaner (Norway);
Sudan Railways;
Victorian State Railways.

The *New South Wales Railways* and the *South African Railways* have indicated in their replies that their networks comprise but a single system of electric traction, and that no change in this respect is expected within a foreseeable future. Nor do they anticipate that there will be any transition points between their systems and a different electric traction system of a neighbouring country. The problem of polycurrent motor motive power units is therefore unkown in their countries, and is likely to remain so in the foreseeable future.

According to the reply received from the Swedish State Railways *(Kungl. Järnvägsstyrelsen),* their network comprises two

TABLE 2. — **Feed systems of electrified lines** (kilometrage).
(Extracted from « Jahrbuch des Eisenbahnwesens », 1958).

| | *Route kilometrage* | | *D.C.* | | | *Single-phase A.C.* | | | | | *Three-phase A.C.* | *Other systems* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *at reduced frequency* | | | *Industrial frequency 50 or 60 c/s* | | | |
| | *Total* | *Electrified* | *1.5 kV or less* | *3 kV* | *Total* | *16 2/3 c/s* | *25 c/s* | *Subtotal* | | *Total* | | |
| *Europe* | 410 988 | 44 651 | 11 479 | 7 944 | 19 423 | 17 238 | 116 | 17 354 | 1 788 | 19 142 | 1 347 | 4 739 |
| *Africa* | 72 079 | 2 994 | 24 | 2 582 | 2 606 | — | — | — | 345 | 345 | — | 43 |
| *Australia* | 43 539 | 737 | 737 | — | 737 | — | — | — | — | — | — | — |
| *Asia* | 287 187 | 16 315 | 8 951 | 7 206 | 16 157 | — | — | — | 137 | 137 | — | 21 |
| *North- and Central America* | 489 536 | 3 733 | 609 | 1 270 | 1 879 | — | 1 647 | 1 647 | — | 1 647 | — | 207 |
| *South America* | 104 901 | 2 712 | 766 | 1 927 | 2 693 | — | — | — | — | — | 3 | 16 |
| *Total* (world) | 1 408 230 | 71 142 | 22 566 | 20 929 | 43 495 | 17 238 | 1 763 | 19 001 | 2 270 | 21 271 | 1 350 | 5 026 |

TABLE 3. — **Transition points.**

| | *British Railways* | *German Federal Railways* | *Japanese National Railways* | *Netherlands Railways* | *U. S. S. R.* |
|---|---|---|---|---|---|
| *Feed systems adopted.* | 25 kV, 50 c/s<br>6.25 kV, 50 c/s<br>750 V D.C.<br>1 500 V D.C. | Main lines :<br>15 kV, 16. $\frac{2}{3}$ c/s.<br>Experimental line (Black Forest) :<br>20 kV, 50 c/s.<br>Isolated lines with 600-750 V D.C.<br>Hamburg<br>1 200 V D.C. | 1 500 V D.C.;<br>750 V D.C.;<br>600 V D.C.;<br>20 kV, 50 c/s;<br>20 kV, 60 c/s. | 1 500 V D.C. | 3 000 V D.C.<br>25 kV, 50 c/s. |
| *Existing transition points between different systems domestic to the network concerned.* | | Freiburg<br>15 kV 16 $\frac{2}{3}$ c/s and 20 kV, 50 c/s. | Sakunami :<br>1 500 V D.C. and 20 kV, 50 c/s.<br>Kuroiso :<br>1 500 V D.C. and 20 kV, 50 c/s.<br>Maibara :<br>1 500 V D.C. and 20 kV, 60 c/s. | None. transition points. | Ojérelié :<br>300 V D.C. and 25 kV, 50 c/s. |
| *Future transition points between different systems domestic to the network concerned.* | | None. | Fujishiro :<br>1 500 V D.C. and 20 kV, 50 c/s.<br>Moji : | None. | The creation of further transition points must be |

| | | | | | |
|---|---|---|---|---|---|
| *Adoption of a different system is being considered.* | Yes.<br>1 500 V D.C.<br>25 kV (6.25 kV)<br>50 c/s. | No. | | The possibility of a future change - over to A.C. feed cannot be excluded. | No. |
| *Transition points with networks of other Administrations.* | | Basel-CFF<br>Bregenz<br>Passau<br>Salzburg<br>Kufstein<br>Mittenwald } ÖBB | None. | 1 500 V -<br>3 000 V D.C.<br>Rosendaal<br>(SNCB). | None. |
| *Future transition points with networks of other Administrations.* | None. | With France<br>at Überherrn.<br>Between<br>Saarbrücken<br>and Stieringen-<br>Wendel.<br>15 kV, 16 $\frac{2}{3}$ c/s<br>and 25 kV,<br>50 c/s. | None<br>at present. | (*a*) with<br>Belgium :<br>(1 500 -<br>3 000 V D.C.<br>Maastricht-<br>Liège (transition<br>point on open<br>line).<br>(*b*) with<br>Germany :<br>(1 500 V D.C. -<br>15 kV).<br>Venlo -<br>Kaldenkirchen<br>Nijmegen -<br>Kleve<br>Arnhem -<br>Emmerich<br>Oldenzaal -<br>Bentheim<br>(transition point<br>in station<br>or on open line). | None. |

electrified systems, viz. 15 kV, 16 2/3 c/s single-phase A.C. which is the predominant system, and 1 500 V and 1 350 V D.C., respectively, on the narrow-gauge lines Stockholm-Norrtällje and Stockholm-Saltsjöbaden. But these systems have no connection with each other.

Although the problem of polycurrent motor motive power units is therefore not yet topical in Sweden, it might become so in future, e.g. if a direct connection should be created, by means of a bridge or a tunnel, between the Swedish and the Danish Railways. It is therefore planned to equip a few single-phase locomotives with silicon rectifiers and D.C. motors in order to gather some experience in this field.

Five of the Administrations and one associated organisation corresponding in the English language have indicated the existence of transition points between different systems of electric traction, either within their own network, or in connection with a contiguous network. These are :

British Railways (BR) (Great Britain);
Deutsche Bundesbahn (DB) (Western Germany);
Japanese National Railways (JNR);
Nederlandsche Spoorwegen (NS) (Netherlands);
U. S. S. R.;
Association of American Railroads.

The *Association of American Railroads* has expressed the opinion that it would have been preferable for the questionnaire to be answered by a railway administration proper. Even so, the Association was good enough to oblige with a brief statement. Some information contained in this statement has been embodied in the present report.

The USSR Railways have only replied to the general questions contained in the questionnaire.

The four other Administrations have answered the whole of the questionnaire.

## 3. SITUATION OF THE TRANSITION POINTS.

Table 3 contains a synopsis of the replies received from British Railways, the German Federal Railways, the Japanese National Railways, the Netherlands Railways, and from the USSR to the first seven questions relating to the position of the transition points and the different systems of current involved.

3.1. *Transition points domestic to the network concerned.*

The single-phase A.C. network of *British Railways* is operated with two different voltages : 25 kV and 6.25 kV. This dualism has been necessitated by the restrictions of electrical clearances encountered in Great Britain.

Their normal services include trains which can work with both voltages. In order to work with 6.25 kV, the primary windings of the transformer are divided into four equal sections. The reconnection is automatically actuated by magnetic apparatus located by the line side.

As regards the future, British Railways anticipate the need for rolling stock capable of working on 750 V D.C. lines equipped with third rail as well as on 25 kV single-phase A.C. lines with overhead equipment.

The *German Federal Railways,* too, have a transition point within their own network, viz. at Freiburg, where the standard 15 kV, 16 2/3 c/s system links up with the Höllental Railway Freiburg-Neustadt which has a 20 kV, 50 c/s traction system. They also operate a 1 200 V D.C. system in the Hamburg area; they reckon, however, that the transition point at Freiburg will remain the only one within their own network.

The *Japanese National Railways* (JNR) possess, apart from some small networks working with 750 or 600 V D.C., a widespread network working with 1 500 V D.C. and, in addition, a gradually expanding A.C. network working with 20 kV, 50 c/s or 20 kV, 60 c/s. These systems are contiguous, and there are already three transition points within the JNR network.

These are tabulated below :

| *Number* | *Name of station where transition point is located* | *Name of lines and their current system* | *Method of transition* |
|---|---|---|---|
| 1 | *Sakunami* | Senzan line 1 500 V D.C. and 20 kV, 50 c/s A.C. | Direct connection at a station, with a change-over section on the line. The change-over takes place while the train is stationary. In addition, there is a neutral section on the open line for experimental purposes. |
| 2 | *Kuroiso* | Tohoku line 1 500 V D.C. and 20 kV, 50 c/s A.C. | Direct connection at a station, with a change-over section on the line. The change-over takes place while the train is stationary |
| 3 | *Maibara* | Between the Tokaido main line (1 500 V D.C.) and the Hokuriku main line (20 kV, 60 c/s A.C.) | Indirect connection by means of a section without overhead equipment where a steam locomotive is used. |

In the near future, JNR expect to create the following two additional transition points :

| *Number* | *Name of station where transition point is located* | *Name of lines and their current system* | *Method of transition* |
|---|---|---|---|
| 4 | *Fujishiro* | Joban line 1 500 V D.C. and 20 kV, 50 c/s A.C. | For passenger trains. Direct connection with a gap on the open line with a non-energized neutral section. The change-over takes place on the locomotive while the train is in motion. |
| 5 | *Moji* | Between the Sanyo main line (1 500 V D.C.) and the Kagoshima main line (20 kV, 60 c/s A.C.) | For all trains. Direct connection with a gap on the open line with a non-energized neutral section. The change-over takes place on the locomotive while the train is in motion. |

Later on, as a result of the further expansion of the A.C. electrification system, the JNR expect to have to create at least another three transition points, though the precise method of transition still remains to be decided. These points will be :

*a*) near Fukushima station, between the Tohoku main line which is to be electrified at 20 kV, 50 c/s A.C., and the

Ou main line, already electrified at 1 500 V D.C.;

*b*) at a point on the Hokuriku main line, linking the western section electrified at 20 kV, 60 c/s with the eastern section electrified at 20 kV, 50 c/s;

*c*) at a point on the eastern section of the Hokuriku main line, linking up with the Shin-etsu main line which is mostly electrified at 1 500 V D.C.

In addition, the JNR have a new line, known as the Tokaido trunk line, under construction which is scheduled for completion within five years, and which will be electrified at 25 kV, 50 or 60 c/s. There will, however, be no transition points since the new line has a gauge of 1 435 mm whilst the other lines have the Japanese standard gauge of 1 067 mm.

In the *Soviet Union,* the predominant electrification system is 3 000 V D.C. There used to be a few suburban lines electrified at 1 500 V D.C. but these have just been converted to 3 000 V D.C. Since 1956, the 137 km long line from Ojérelié to Pavelez has been experimentally operated with 25 kV, 50 c/s single-phase A.C. so that a transition point is now in existence at Ojérelié. It is, however, expected that further transition points will have to be created in the future as a result of the further expansion of the 25 kV, 50 c/s system.

3.2. *Transition points with other networks.*

Apart from their own transition point at Freiburg, the *German Federal Railways* (DB) also have transition points with other networks, viz. with those of the Austrian Federal Railways (ÖBB) and of the Swiss Federal Railways (CFF); but these networks are, like that of the German Federal Railways, equipped for 15 kV, 16 2/3 c/s. In the near future, however, the DB expect to have to create two transition points with the 25 kV, 50 c/s system of the SNCF viz. one at Überherrn in the Saarland, and one between Saarbrücken and Stieringen-Wendel.

The *Netherlands Railways* have no transition point domestic to their own network which is exclusively electrified at 1 500 V D.C. But they have, at Rosendaal, a transition point with the 3 000 V D.C. system of the SNCB, and they anticipate the need for the creation of further transition points: one with the SNCB between Maastricht and Liège, and several others with the 15 kV, 16 2/3 c/s system of the German Federal Railways, e.g. between Arnhem and Emmerich.

3.3. *METHOD OF TRANSITION.*

*When can vehicles with multi-current motors be regarded as the proper solution?*

In the opinion of the *German Federal Railway,* the use of motive power units with polycurrent motors represents the simplest solution from an operating point of view. But such vehicles are always more expensive than conventional motive power units. Their use must therefore remain confined to those services where through operation is vitally necessary for operating reasons.

Where the use of motive power units with poly-current motors has been decided upon, an effort should be made to reduce the number of systems as much as possible. With multiple-unit trains destined for international services, however, it is also necessary to have regard to electrification systems which are not directly contiguous.

In the opinion of the *Japanese National Railways,* passenger traffic by means of multiple unit trains is continually increasing. They anticipate the need, in the future, for multiple-unit sets capable of working on two different current systems, thus obviating the need for passengers to change trains.

As regards passenger traffic carried in multiple-unit trains passing over their numerous transition points between 25 and 6.25 kV, *British Railways* have finally decided to use dual-voltage sets, a solution

which, in their case, is regarded as fully justified. Similar arrangements will be made for locomotives operating under the same conditions.

As regards passenger traffic carried in locomotive-hauled trains, the *Japanese National Railways* are of the opinion that the change of locomotives represents the more economic solution. However, if a line is used by a great number of multiple-unit trains equipped for working on two systems, whilst the number of locomotive-hauled trains is relatively small, it would be more economic to equip these few locomotives for dual-system operation as well.

Even for goods trains, the *Japanese National Railways* regard the use of dual-system locomotives as justiifed, e.g. if these locomotives must also be able to haul passenger trains and must, even for that reason alone, be equipped for through working.

The traffic density is regarded as an important factor. If the density is low, it would be more economic to change locomotives, and the extra time required for this operation would normally be available in view of the comparatively small number of through trains. Where locomotives are changed, it must be possible to switch over a section of the overhead line from one system to the other. In consequence, the overhead system should preferably be simple, i.e. the change-over should preferably take place at a small station. If, on the other hand, the overhead system at the transition point happens to be extensive, this may well constitute a valid reason to forgo locomotive change and use polycurrent motive power units instead.

If motive power units with polycurrent motors are provided, the transition should preferably take place on the open line. It may consist of a short section without any overhead equipment (as between NS and SNCB), or of a gap comprising one or more neutral sections (British Railways) or even of an earth-connected section flanked by neutral sections.

## 4. TECHNICAL DATA OF ROLLING STOCK IN OPERATION OR UNDER CONSTRUCTION.

The leading data supplied by the administrations corresponding in the English language are tabulated in Table 4, and the locomotives and multiple-unit trains described in this table are schematically illustrated in Appendices 1 to 7.

The locomotives and multiple-unit trains already in existence or still in the design stage can be divided into four categories, according to whether they are designed for :

*a*) two D.C. systems (NS/SNCB);

*b*) two A.C. systems (BR) or three A.C. systems (DB);

*c*) one D.C. system and one A.C. system (JNR);

*d*) two D.C. and two A.C. systems (NS/SBB).

All systems make use of *D.C. traction motors* which, when working on D.C. systems, are fed directly and, when working on single-phase A.C., are fed through a transformer and one or more rectifier sets. In this connection, it is note-worthy that the locomotives of the German Federal Railways as well as the motive power units of British Railways, though exclusively fed by A.C., are nevertheless equipped with D.C. motors.

### 4.1. *Voltage regulation.*

On all systems where D.C. feed must be taken into account, the voltage of the traction motors is regulated by means of resistances which are incorporated in the D.C. circuit and can be cut out progressively.

It is only on the motive power units exclusively designed for A.C. feed (DB and BR) that the voltage is regulated at the primary side (DB) or secondary side (BR) of the transformer.

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| | *JNR (Japan) Locomotive ED 46 (Appendix 1)* | *JNR (Japan) Locomotive EF 30 (Appendix 2)* | *JNR (Japan) Train set A (Appendix 3)* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *First year of operation.* | Ready in 1959. | Ready in 1959. | Trial runs proceeding. | Trial runs proceeding. |
| *Number of units.* | 1 | 1 | 1 | 1 |
| *Destined for :* | Passenger service. | Passenger and goods service. | Passenger service. | Passenger servi |
| *Weight.* | 64 tons. | 96 tons. | 34 + 44.5 tons (motor coach). | 34 + 44.5 ton (motor coach) |
| *Axle arrangement.* | BB. | BBB. | 2 + 2, BB. | 2 + 2, BB. |
| *Current supply system.* | 1 500 V D.C.<br>20 kV, 50 c/s. | 1 500 V D.C.<br>20 kV, 60 c/s. | 1 500 V D.C.<br>20 kV, 50 c/s. | 1 500 V D.C.<br>20 kV, 50 c/s |
| *Traction motor feed.* | D.C. : direct feed.<br>A.C. : transformer and 4 excitrons. | D.C. : direct feed.<br>A.C. : transformer and silicon rectifier. | D.C. : direct feed.<br>A.C. : transformer and 4 ignitrons. | D.C. : direct fe<br>A.C. : transfor<br>and 2 excitron |
| *Regulation of traction motor voltage.* | Starting resistances in D.C. circuit. | Starting resistances in D.C. circuit. | Starting resistances in D.C. circuit. | Starting resistances in D circuit. |
| *Power rating.* | 1 820 H.P. | — | | |
| *Continuous rating :* | | | | |
| *One-hour rating.* | 1 970 H.P. | 2 400 H.P. | 470 H.P. | 470 H.P. |
| *Starting power.* | 19.2 tons. | 33.6 tons. | 760 H.P. | 760 H.P. |
| *Number of motors.* | 1 per bogie;<br>Total : 2 motors. | 1 per bogie;<br>Total : 3 motors. | 2 per bogie;<br>Total : 4 motors. | 2 per bogie;<br>Total : 4 moto |
| *Transmission.* | Individual drive with single gear reduction. | Individual drive with double gear reduction. | Individual drive. | Individual driv |
| *Number of pantographs.* | 1 for 1 500 V D.C. and 20 kV A.C. | 1 for 1 500 V D.C. and 20 kV A.C. | 1 for 1 500 V D.C. and 20 kV A.C. | 1 for 1 500 V D and 20 kV A. |
| *Reserve :* | 1 reserve. | 1 reserve. | No reserve. | No reserve. |

| *DB (Germany) Locomotive E 320 (Appendix 5)* | *NS/SNCB (Benelux) Train sets (Appendix 6)* | *NS/CFF (TEE) Train sets (Appendix 7)* | *BR (Britain) Train sets* |
|---|---|---|---|
| Ready in 1959/60. | In service since 1957. | In design stage. | 1958 and later. |
| 3 (one of them being described). | 8 NS.<br>4 SNCB. | 2 | 112 motor coaches in service or under construction, 197 on order. |
| Passenger and goods service | Passenger service. | Passenger service. | Passenger service. |
| 84 tons (BB). | 115 tons (2 coaches). | 190 tons (4 coaches). Motor coach 72 tons (including luggage and staff compartment). | 142 tons (4 coaches). Motor coach 54 tons. |
| BB. | B + 2, 2 + B. | BB 2 + 2, 2 + 2, 2 + 2. | BB 2 + 2, 2 + 2, 2 + 2. |
| 15 kV, 16.⅔ c/s.<br>20 kV } 50 c/s.<br>25 kV } | 1 500 V D.C.<br>3 000 V D.C. | 1 500 V D.C.<br>3 000 V D.C.<br>15 kV 16 ⅔ c/s.<br>25 kV, 50 c/s. | 25 kV, 50 c/s.<br>6.25 kV, 50 c/s. |
| A.C. only; motor current supplied through transformer and silicon rectifier. | Both systems : direct feed. | D.C. : direct feed.<br>A.C. : transformer and silicon rectifier. | Motor feed exclusively through transformer and excitrons. |
| Regulation on primary side of transformer. | Starting resistances in D.C. circuit. | Starting resistances in D.C. circuit. | Regulation on secondary side of transformer. |
| 3 180 H.P. | 832 H.P. | — | 800 H.P. per motor coach. |
| 3 520 H.P.<br>3 420 H.P.<br>3 370 H.P.<br>respectively. | 1 000 H.P. | 2 000 H.P. (at traction motor shaft). | |
| 28 tons. | 5.25 tons. | Max. : 18 tons. | 12 tons. |
| 2 per bogie; Total : 4 motors. | 2 per bogie; Total : 4 motors. | 2 per bogie; Total : 4 motors. | 2 per bogie; Total : 4 motors (in each motor coach). |
| Two side drive (individual). Tram suspension. | Individual drive. Tram suspension. | Individual drive. Brown-Boveri spring drive. | Individual drive. |
| 1 for 15 kV;<br>1 for 20 kV;<br>1 for 25 kV. | 1 for 1 500 V C.C. (NS).<br>1 for 3 000 V C.C. (SNCB). | 1 for :<br>1 500 V (NS)<br>3 000 V (SNCB + CFL)<br>1 for :<br>15 kV (CFF) +<br>25 kV (SNCF + CFL) +<br>3 000 V (FS)<br>1 for :<br>15 kV (DB + ÖBB). | 1 for { 6.25 kV / 25 kV |
| Reserve bows only. | No reserve. | No reserve. | No reserve. |

TA

| | *JNR (Japan) Locomotive ED 46* | *JNR (Japan) Locomotive EF 30* | *JNR (Japan) Train set A* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *Pantograph application pressure.* | 5.5 kg | 5.5 kg | 4.5 kg | 4.5 kg |
| *Number of strips per bow.* | 4 per bow. | 4 per bow. | 2 per bow. | 2 per bow. |
| *Number of bows per pantograph.* | 2 | 2 | 2 | 2 |
| *Material used for strips.* | Copper 80 %.<br>Tin : 10 %.<br>Iron : 5 %.<br>Graphite : 5 %. | See ED 46, col. 1. | See ED 46, col. 1. | See ED 46, col. |
| *Lubrication.* | Grease lubrication. | Grease lubrication. | — | — |
| *Maximum current per pantograph.* | 1 500 amps. | 1 500 amps. | 500 amps. | 500 amps. |
| *Choice of system : manual or automatic.* | After manual operation of selector switch, the equipment is only switched over when the voltage relay concerned is energized. | See ED 46, col. 1. | See ED 46, col. 1. | See ED 46, col. |
| *Control by pantograph.* | No. | No. | No. | No. |
| *Safety devices to prevent choice of wrong system.* | A.C. main circuit breaker opened by operation of D.C. over-voltage relay if D.C. installation is connected with A.C. supply. In the reverse case the main fuse (D.C. current) will blow. | | | |
| *On which components does the selection device acts ?* | The selection device acts on both main circuit breakers on the main current circu and on the current supply for the auxiliaries. | | | |

*ntinued).*

| *DB (Germany)*<br>*Locomotive E 320* | *NS/SNCB (Benelux)*<br>*Train sets* | *NS/CFF (TEE)*<br>*Train sets* | *BR (Britain)*<br>*Train sets* |
|---|---|---|---|
| 8 kg dyn.<br>9 kg dyn. | 1 500 V : 9.5 kg.<br>3 000 V : 7.5 kg. | Yet to be decided. | 9 kg |
| 2 per bow with both pantographs. | 1 500 V : 3<br>(incl. 1 short).<br>3 000 V : 2. | No. 1 : 3<br>(incl. 1 short).<br>No. 2 : 2.<br>No. 3 : 2. | 2 per bow. |
| 1 | 1 | No. 1 : 2.<br>No. 2 : 1.<br>No. 3 : 1. | 1 |
| No. 1 : Graphite (no lubrication).<br>No. 2 : Steel (possible lubrication according to SNCF system). | 1 500 V : Graphite impregnated with copper + lead.<br>3 000 V : Graphite lubricated. | Yet to be decided. | Graphite, special mixture.<br>No lubrication. |
| 20 amps. with 15 kV.<br>45 amps. with 20 kV.<br>75 amps. with 25 kV. | 1 500 V : 900 amps.<br>3 000 V : 450 amps. | Yet to be decided. | 300 amps. with 6.25 kV. |
| fter manual operation of selector switch the equipment is switched over directly.<br>Yes. | dto.<br>Yes. | dto.<br>Yes. | Automatically, by means of magnetic inductions laid outside the running rails, placed before and after the neutral section.<br>No. |
| Main circuit breaker tripped if wrong system selected. | No main circuit breaker but connection prevented due to blocking by voltage relay. | Main circuit breaker tripped if wrong system selected. | Main circuit breaker can only be closed if correct system choice is verified by voltage relay. |
| The selection device ts on the transformer tappings and on the safety devices. | The selection device acts on traction circuit and motor-generator-compressor. | The selection device acts on the traction circuit, the (secondary) transformer tappings and on the motor-generator group. | The selection device acts on the connection of the primary transformer windings :<br>4 windings in series for 25 kV;<br>windings in parallel for 6.25 kV. |

TABLE

| | *JNR (Japan) Locomotive ED 46* | *JNR (Japan) Locomotive EF 30* | *JNR (Japan) Train set A* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *Effect of switch-over operation.* (a) *on the traction motor circuit;* | No change in traction motor circuit. | D.C. : 3 motors in series; 3 motors in parallel. A.C. : 3 motors in series; 2 motors in series(!). | No change in traction motor circuit. | No change in traction motor circuit. |
| (b) *on the auxiliaries circuit;* | Rectifier fan motor switched from A.C. to D.C. or vice versa; otherwise no change. | A.C. auxiliary motors are fed by A.C. feed only. The other auxiliary motors retain the same feed, irrespective of A.C. or D.C. supply. | | |
| (c) *on the train heating circuit;* | A.C. : direct from transformer (1 500 V A.C.). D.C. : also 1 500 V A.C.; through inversely operating rectifier. | No train heating circuit provided. | No change. | No change. |
| (d) *on any other circuit.* | — | — | — | — |
| *Verification of correct system, and protection against selection of wrong system.* | The main circuit breaker (ABB) can only be closed when hand selector switch, H.T. selection switches and voltage relays are in the correct position. | | | |
| *Number and type of main circuit breakers; safety functions.* | 1 A.C. airblast circuit breaker. Overload on primary side of transformer. Earth on secondary side of transformer. Back-fire in rectifier of transformer. Also D.C. high-speed circuit breaker for overload on circuit. | See ED 46, col. 1. dto. dto. Overload on rectifier. See ED 46, col. 1. | See ED 46, col. 1. dto. dto. Back-fire, rectifier. No D.C. highspeed circuit breaker, but group of 4 line circuit breakers with resistances. | See ED 46, col. 1. dto. dto. dto. dto. |

*ntinued).*

| *DB (Germany)* *Locomotive E 320* | *NS/SNCB (Benelux)* *Train sets* | *NS/CFF (TEE)* *Train sets* | *BR (Britain)* *Train sets* |
|---|---|---|---|
| No change in the connection scheme. The correct feed voltage is obtained by transformer regulation. | 1 500 V : Series parallel : 2 × 2 motors. Parallel : 4 × 1 motor. 3 000 V : Series : 1 × 4 motors. Series-parallel : 2 × 2 motors. Motor-generator-compressor group motors : 1 500 V parallel; 3 000 V series. Two heating circuits per vehicle : 1 500 V parallel; 3 000 V series. | 1 500 V D.C., + 15 kV and 25 kV A.C. : Series/Parallel : 2 × 2 motors. Parallel : 4 × 1 motor. 3 000 V D.C. : Series : 1 × 4 motors. Series-parallel : 2 × 2 motors. Motor-generator group motors in series for 3 000 V, otherwise in parallel. Heating and air-conditioning provided by motor-generator group. No change. | No change. The correct feed voltage is obtained by changing the primary side of the transformer. |
| The switchover connects the corresponding voltage or frequency relays. | — | — | — |
| None. | Yes. The pantograph not forming part of the system cannot be raised, and the line circuit breakers cannot be closed (voltage relays). | Yes. The main circuit breaker can only be closed when selection gear and voltage relay agree with the feed voltage. | Main circuit breaker can only be closed if correct system choice is verified by voltage relay. |
| high-speed air-blast circuit breaker : Overload on primary side of transformer. Overload on heating circuit. Earth leakage. Low feed voltage. Erroneous choice of system. | No main circuit breaker, but a set of 2 line circuit breakers for traction. | 1 high-speed air-blast circuit breaker : Wrong choice of system (A.C.). Overload on primary side of transformer. Earth leakage. Zero voltage. Overload rectifier. 1 D.C. high-speed circuit breaker : Wrong choice of system (D.C.). Overload on circuit. Zero voltage. | 1 A.C. air-blast circuit breaker : Transformer fault. Rectifier fault (temperature, back-fire, overload). |

TAB

| | *JNR (Japan) Locomotive ED 46* | *JNR (Japan) Locomotive EF 30* | *JNR (Japan) Train set A* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *Over-voltage protection.* | In main circuit breaker (ABB) : non-linear resistance (acting at double voltage). In addition : A.C. lightning arrester (40 kV at 50 c/s, 20 000 amps. at 15 micro-secs). D.C. lightning arrester (3 700 V at 50 c/s, 1 500 amps. at 15 micro-secs). | | | |
| *Secondary transformer voltage.* | 2 × 2 080 V. | 1 800 V. | 1 855 V. | 1 820 V (no-load). |
| *Transformer cooling.* | Separate ventilation, with oil pump, radiator and fan. | Self-ventilation, without oil pump. | Self-ventilation, with oil pump. | Separate ventilation with oil pump, radiator and fan. |
| *Effect of rectifier on transformer.* | 10 % heavier. 141 % winding capacity. | Same as normal transformer. | Same as normal transformer. | 10 % heavier. 141 % winding capacity. |
| *Measures to reduce weight.* | Radial core to save space and weight; silicon steel plates. | No special measures. | Shell-type transformer. | Radial core to save space and weight. |
| *Tertiary transformer windings.* | For A.C. auxiliary circuits : 20 kVA, 465 V. For train heating : 465 kVA-1 590-1 060 | No separate windings for auxiliaries. (No train heating.) | No separate windings. | For heating : 23 kVA - 1 515 V. For A.C. auxiliary motor : 5 kVA - 206 V. For rectifier ignition 4 kVA, 69 V. |
| *Type of transformer winding.* | Primary windings : disc windings. Secondary windings : cylindrical coils (robust, with a view to back-fire). | Shell type transformer. Disc winding. | Primary and secondary winding alternately in four groups (underfloor type). | As for locomotive ED 46. |
| *Transformer regulation.* | No transformer regulation. | None. | None. | None. |
| *D.C. traction circuit control.* | 12 in series (1 for weak field during start). 13 in parallel (6 for weak field). | 11 in series (with D.C. supply). 8 in parallel (with D.C. supply). A.C. : 11 with 3 motors (series). 8 with 2 motors (series) Also Vernier control. | 5 in series; 4 in parallel (1 for weak field). | |

*ntinued).*

| *DB (Germany) Locomotive E 320* | *NS/SNCB (Benelux) Train sets* | *NS/CFF (TEE) Train sets* | *BR (Britain) Train sets* |
|---|---|---|---|
| Possible installation of voltage-controlled resistance with spark gap. 45-52.5 kV. | Over-voltage protection of condenser type. | Not yet decided. | None. |
| ract. motor : 1 000 V. eat. : 1 500 V-100 V. uxiliaries : 245-251 V. | — | Approx. 1 800 V. | 11 tappings, max. 1 875 V min. 199 V. |
| Separate ventilation, with oil pump, radiator and fan. | — | Separate ventilation with oil pump, radiator and fans. | Separate ventilation with oil pump, radiator and fans. |
| 20 % higher power. | — | — | Designed as rectifier transformer. Effect on weight not known. |
| Main winding differential connection. | — | — | No special measures. |
| Train heating and auxiliaries, separate windings. | — | No separate windings for auxiliaries. | For auxiliaries and heating : 48 kVA, 240 V. |
| — | — | — | — |
| 39 notches at 15 kV; 33 notches at 20 kV; 27 notches at 25 kV; by means of contact lide on primary side. | — | No transformer regulation. | Regulation by 11 tappings on secondary side, for 25 kV as well as 6.25 kV. |
| ach motor hat its own ransformer winding and rectifier. weak field position. | Series/parallel (series) : 7 steps; Parallel (series/parallel) : 6 steps. | Yet to be decided. | None. |

TABL

| | *JNR (Japan) Locomotive ED 46* | *JNR (Japan) Locomotive EF 30* | *JNR (Japan) Train set A* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *Contactor system.* | Individual electro-pneumatic contactors. | Individual electro-pneumatic contactors. For Vernier control motor-operated cam-switches. | Pneumatically operated cam drum. | |
| *Series-parallel change-over.* | Short-circuit method. | Short-circuit method. | Free connection of 1 pair of motors. | |
| *Field weakening.* | Series 40 %. Parallel 40 and 60 %. | No field weakening. | Parallel 40 %. | Parallel 40 %. |
| *Field weakening method.* | Tapping. | No field weakening. | Tapping. | Tapping. |
| *Type of rectifier.* | Sealed-off. Excitrons (4 tanks). Forced ventilation, pumpless, 1 anode. | Silicon rectifier. Forced ventilation. | Sealed-off ignitrons (4 tanks), pumpless, forced water/air cooling (1 anode). | Sealed-off excitrons (2 tanks). Forced ventilation (1 anode). |
| *Rated power.* | 1 560 kW (1 500 V, 1 040 amps. for 4 tanks). | 4 × 450 kW (2 × 1 500 V, 2 × 300 amps.). | 568 kW (1 500 V, 379 amps. for 4 tanks). | 620 kW (1 500 V, 413 amps. for 2 tanks). |
| *Peak rating.* | 2 450 V, 1 640 amps. (for 2 tanks). | 8 400 V (350 V × 24). | 2 000 V, 1 000 amps. 1 second. | 2 000 V, 670 amps. (2 tanks). |
| *Continuous rating.* | 1 500 V, 1 040 amps. | 62.5 V, 100 amps. per element. | 1 500 V, 400 amps. (4 tanks). | 1 500 V, 413 amps. |
| *Overload.* | 2 400 amps. (1 min.). | 2×300 amps.-10 mins. 2×560 amps.-30 sec. | 130 %, 15 mins.; 200 %, 15 secs. | 660 amps. - 30 sec. (160 %). |
| *Voltage drop.* | Current 100 % voltage drop 23 V; 50 % - 22 V; 10 % - 21 V. | 1.1 - 1.3 V (at 100 % load), per element. | 100 % - 18.7 V; 75 % - 18 V; 50 % - 17 V. | 100 % - 22 V; 50 % - 18 V; 10 % - 17 V. |
| *Efficiency.* | N = 98.4 %. | N = 95 %. | N = 97.8 %. | N = 98 %. |

*tinued).*

| *DB (Germany) Locomotive E 320* | *NS/SNCB (Benelux) Train sets* | *NS/CFF (TEE) Train sets* | *BR (Britain) Train sets* |
|---|---|---|---|
| Field-weakening th contactors only. | Contactors operated by cam-shaft driven by electric motor. | Contactors operated by motor-driven camshaft. | — |
| rmanently parallel. | Bridge connection. | Short-circuit method. | — |
| 41.6 %. | 45 %. | Several weak field steps. | 40 % |
| Inductive shunt. | Inductive shunt. | Inductive shunt. | Tapping. |
| Silicon rectifier. orced ventilation ared with traction motor). | — | Silicon rectifier. Forced ventilation. | Excitrons, 4 tanks. Forced ventilation, air-cooled (1 anode). |
| 600 kW, 1 000 V. 0 amps. per rectifier (Total : × 4). | — | Yet to be decided. | 1 000 kW, 1 500 V 666 amps. |
| 00 V, 1 600 amps. | — | | 2 000 V, 1 000 amps. |
| 00 V, 1 600 amps. | — | | 1 500 V, 666 amps. |
| No overload. | — | | 2 × continuous rating (1 minute). |
| Yet to be decided. | — | | 20 V. |
| et to be decided. | — | | 98 %. |

TABL

| | *JNR (Japan) Locomotive ED 46* | *JNR (Japan) Locomotive EF 30* | *JNR (Japan) Train set A* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *Rectifier connection.* | 1-phase full wave. | 1 phase double bridge. | 1 phase bridge. | 1-wave full-wave. |
| *Anode heating.* | Electric anode heating with D.C. and A.C. | — | Electric anode heating with D.C. and A.C. | Electric anode heatin with D.C. and A.C. |
| *Vacuum pump.* | No vacuum pump. | — | No vacuum pump. | No vacuum pump. |
| *Grids.* | 1 grid for ionisation; 1 grid to prevent overvoltage. | — | 1 grid for ionisation. | 1 grid for ionisation; 1 grid to prevent overvoltage. |
| *Rectifier pre-heating.* | Cathode heating for D.C. and A.C. | — | Heating by electrically heated water with D.C. and A.C. | Cathode and tank pre-heated with D.C and A.C. |
| *Rectifier cooling.* | Air, 200 m³/min. 85 mm water column (4 tanks). | Air, 60 m³/min. 20 mm water column (2 ×). | Water, 150 litres pr. minute, 12 m water column. | Air, 40 m³/min. 20 mm water column |
| *Rectifier auxiliary power :* | | | | |
| *Continuous.* | a. 14 kW | 1.5 kW | 5 kW | 3 kW |
| *Maximum.* | b. 53 kW | 1.5 kW | 19.5 kW | 21 kW |
| *Rectifier protection.* | Temperature (high and low). Backfire. | Overload. Rupture. | Temperature. Backfire and overload. Rupture. | Temperature. Backfire. Rupture. |
| *Protective action.* | Backfire : main circuit breaker opened. Temperature : grid « opened ». Earth on tank : Main circuit breaker opened by earth fault relay. | Overload : main circuit breaker opened. | Temperature : rectifier control circuit opened. Backfire and overload : main circuit breaker opened. Earth fault : dto. (earth relay). | Same as for train set A. |
| *Weight/H.P. ratio.* | 2 770 kg (2 090 H.P.) 1.33 kg/H.P. | 1.33 kg/H.P. | 2.75 kg/H.P. | 0.88 kg/H.P. |
| *Smoothing coil.* | Smoothing coil. | Yes. | Yes. | Yes. |
| *Ripple voltage.* | Ripple 20 %. | 20 % | 18 % | 20 % |
| *Type of traction motor.* | Series motor : commutation poles compensation winding, half-enclosed; forced ventilation; one armature, one commutator. | Same as for loco. ED 46. | Normal self-ventilated motor adapted for D.C. with ripple voltage. Band not magnetized, compole cores laminated, split-type brushes. | Same as for motor unit B. |

*ntinued).*

| *DB (Germany) Locomotive E 320* | *NS/SNCB (Benelux) Train sets* | *NS/CFF (TEE) Train sets* | *BR (Britain) Train sets* |
|---|---|---|---|
| Bridge connection. | — | Bridge connection. | 1 phase full-wave, 1 in series 2 in parallel. |
| — | — | — | None. |
| — | — | — | None. |
| — | — | — | 1 grid for limiting backfire. |
| — | — | — | Hot air. |
| Air cooling output not stated). | — | Air cooling (output not stated). | Air cooling (output not stated). |
| Approx. 1 kW. | — | Not yet determined. | 1 kW |
| Temperature. Short-circuit. upture. Overload. | — | Overload. Rupture. Short-circuit. | Temperature. Backfire. Overload. |
| Special high-speed circuit breaker. | — | Overload : D.C. circuit cut out. Otherwise : Main circuit breaker tripped. | Main circuit breaker opened. |
| 0.765 kg/H.P. | — | — | — |
| Yes. | — | Smoothing coil. | Smoothing coil. |
| Not yet known. | — | Not yet known. | Not yet known. |
| Series motor, 1 commutator, 1 armature. Forced ventilation nd self-ventilation. mpensation winding. | Series motor, 1 commutator, 1 armature. Self-ventilated. | Series motor, 1 armature. Compensation winding. | Series motor, 1 commutator, 1 armature. Self-ventilating. No compensation winding. |

TABLE

| | *JNR (Japan) Locomotive ED 46* | *JNR (Japan) Locomotive EF 30* | *JNR (Japan) Train set A* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *Traction motor rating and weight.* | Continuous rating 700 kW - 3 250 kg. | One-hour rating 600 kW - 3 200 kg. | Continuous rating 90 kW One-hour rating 142 kW - 2 200 kg. | Same as for train set A. |
| *Motor insulation.* | Main poles : Class H. Otherwise : Class F. | Armature : B. Field : F. | B. | B. |
| *Structural features.* | Stator not laminated. Main poles laminated. Commutation poles laminated. Compensation winding. 4 poles. | Stator not laminated. Main poles laminated. Commutation poles not laminated. No compensation winding, 4 poles. | Stator not laminated. Main poles laminated. Commutation poles laminated. No compensation. 4 poles. | Stator not laminated. Main poles laminated. Communication poles laminated. No compensation. 4 poles. |
| *Type of armature winding.* | Lap winding. | Lap winding. | Wave winding. | Wave winding. |
| *Number of commutation segments.* | 410 | 420 | 245 | 245 |
| *Maximum voltage between segments.* | 18 V. | 18.1 V. | 14.7 V. | 14.6 V. |
| *Brushes.* | Triple. | Double. | Double. | Double. |
| *Measures concerning ripple.* | Compole cores laminated. Split brushes. | No special measures. | Non-magnetized band. Compole cores laminated. | Non-magnetized band. |
| *Special measures for poly-current operation.* | Elastic drive not necessary. Main poles laminated. Shunting of main poles not required if ripple is sufficiently suppressed. | Same as for loco ED 46. | Split brushes. Same as in col. 2. | Compole cores laminated. Split brushes. Same as in col. 2. |
| *Electric brake.* | None. | None. | None. | None. |

*ntinued).*

| *DB (Germany)*<br>*Locomotive E 320* | *NS/SNCB (Benelux)*<br>*Train sets* | *NS/CFF (TEE)*<br>*Train sets* | *BR (Britain)*<br>*Train sets* |
|---|---|---|---|
| One-hour rating<br>630 kW -<br>3 200 kg. | Continuous rating<br>153 kW -<br>2 200 kg. | One-hour rating 375 kW. | Continuous rating 186 kW.<br>1 715 kg. |
| B | B | | H |
| tator not laminated.<br>ain poles laminated.<br>Commutation poles<br>not laminated.<br>ompensation winding,<br>6 poles. | Stator not laminated.<br>Main poles laminated.<br>Commutation poles<br>not laminated.<br>No compensation<br>winding, 4 poles. | | Stator not laminated.<br>Main poles laminated.<br>Commutation poles laminated.<br>No compensation winding.<br>4 poles. |
| Lap winding. | Lap winding. | | Lap winding with equalisers. |
| 348 | 322 | | |
| 17.2 V. | 18.6 V. | Yet to be determined. | 252<br>9.85 V. |
| uble and solid brushes<br>(trial).<br>Main pole windings<br>ermanently shunted<br>(4 %). | Double.<br>— | | Double.<br>Main poles<br>and compoles laminated.<br>Split brushes. |
| tic drive not necessary.<br>ain poles laminated.<br>Main poles shunted.<br>moothing coil based<br>on 16. $\frac{2}{3}$ c/s. | —<br>— | | Elastic drive<br>not necessary.<br>Shunting of main poles<br>not required. |
| ields in series excited<br>by separate silicon<br>rectifiers.<br>ction motor armatures<br>by 2 on resistance.<br>Acting on 25, 20<br>and 15 kV.<br>May or may<br>not be combined<br>th pneumatic brake. | None. | 4 fields in series excited<br>by separate brake generator<br>on motor-generator shaft.<br>Each motor armature acting<br>on separate resistance (part<br>of starting resistance).<br>Acting with all current<br>systems. | No electric brake. |

TABL

| | *JNR (Japan) Locomotive ED 46* | *JNR (Japan) Locomotive EF 30* | *JNR (Japan) Train set A* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *Source of supply for auxiliaries.* | *With A.C. feed :* 1 500 V A.C. from transformer; 1 500 V D.C. through rectifier; 440 V, 3-ph., 60 c/s from motor-generator; 440 V, 1-ph. , 50 c/s from transformer; 100 V A.C. from motor-generator through 440/100 V transformer; 100 V A.C. from motor-generator and through 440/100 V transformer and rectifier. | *With A.C. feed :* 1 500 V D.C. through rectifier; 200 V, 3-ph., 60 c/s from motor-generator; 200 V, 1-ph., from transformer; 100 V D.C. from motor-generator. | *With A.C. feed :* 1 500 V D.C. through rectifier; 200 V A.C. from transformer; 100 V A.C. from main transformer through 200/100 V transformer; 100 V D.C. from motor-generator. | *With A.C. feed :* 1 500 V D.C. through rectifier; 200 V A.C. from transformer; 69 V A.C. from transformer; 100 V D.C. from motor-generator. |
| | *With D.C. feed :* 1 500 V A.C. through inverted rectifier; 1 500 V D.C. direct; 440 V, 3-ph. A.C., 60 c/s from motor generator; 100 V D.C. from motor-generator. | *With D.C. feed :* 1 500 V D.C. direct; 220 V, 3-ph., A.C. from motor-generator; 100 V D.C. from motor-generator. | *With D.C. feed :* 1 500 V D.C. direct; 100 V D.C. from motor-generator. | *With D.C. feed :* 1 500 V D.C. direct; 100 V D.C. from motor-generator. |
| *Auxiliaries.* | Motor generator 1 500 V D.C.-440 V, 3-ph., A.C., 60 c/s. | Motor generator 1 500 V D.C.-100 V, 3-ph., A.C., 60 c/s. | Motor generator 1 500 V D.C.-100 V D.C. | Motor generator 1 500 V D.C.-100 V D.C. |
| | 1 cooling fan for rectifiers 440 V, 1-ph., A.C. 50 c/s. | 2 coolings fans for rectifiers 220 V, 1-ph., A.C. 60 c/s. | 2 coolings fans for rectifiers 200 V, 1-ph., A.C. 50 c/s. | 1 cooling fan for rectifiers 200 V, 1-ph., A.C. 50 c/s. |
| | 1 auxiliary fan for rectifier 440 V, 3-ph., A.C., 60 c/s. | — | — | — |
| | 1 cooling fan for transformer 440 V, 3-ph., A.C., 60 c/s. | — | — | 1 cooling fan for transformer 200 V, 1-ph., A.C., 50 c/s. |
| | 2 cooling fans for traction motors 1 500 V D.C. | 3 cooling fans for traction motors 1 500 V D.C. | — | — |
| | 1 cooling fan for resistance and smoothing coil, mounted on motor-generator shaft. | 6 cooling fans for resistances 220 V, 3-ph., A.C., 50 c/s. | — | — |

*tinued).*

| *DB (Germany)*<br>*ocomotive E 320* | *NS/SNCB (Benelux)*<br>*Train sets* | *NS/CFF (TEE)*<br>*Train sets* | *BR (Britain)*<br>*Train sets* |
|---|---|---|---|
| *h 25, 20 and 15 kV :*<br>50 V, 1-ph., A.C.<br>m transformer D.C.<br>oltage not known);<br>transformer through<br>icon rectifier 3-ph.,<br>s (voltage not known,<br>approx. 100 V);<br>V D.C. from motor-<br>ator through rectifier.<br>*With 25 kV :*<br>1 000 V A.C.<br>and 1 500 V A.C.<br>rom transformer.<br>*ith 15 and 20 kV :*<br>1 000 V A.C.<br>rom transformer. | 1 500 V D.C. direct from 1 500 V D.C. supply, or through series connection with 3 000 V D.C. supply;<br>100 V D.C.<br>from motor-generator;<br>220 V, 100 c/s<br>from motor-generator through converter. | 1 500 V D.C. direct from 1 500 V D.C. supply; through main transformer and main rectifier with 15 kV and 25 kV supply; through series connection with 3 000 V D.C. supply; 220/380 V, 3-ph., A.C., 50 c/s from-motor-generator (with all current systems) 100 V D.C. from motor-generator through transformer and rectifier (with all current systems). | *With 25 and 6.25 kV :*<br>240 V, 1-ph., A.C., 50 c/s from transformer 110 V D.C. from transformer through rectifier. |
| or-generator 250 V,<br>A.C., 16 $\frac{2}{3}$ or 50 c/s,<br>V, 3-ph., 50 c/s. | Motor-generator 1 500 V or 3 000 V D.C.-100 V D.C. | Motor-generator 1 500 V or 3 000 V D.C.-220/380 V 3-ph., A.C. | — |
| ling fans for rectifiers<br>o used for traction<br>otor) D.C. motors. | — | Cooling fan for rectifiers 220/380 V, 3-ph., A.C. | Cooling fan for transformer and rectifiers<br>240 V, 1-ph., A.C., 50 c/s. |
| — | — | — | — |
| cooling fan for<br>former D.C. motor. | — | Cooling fan for transformer 220/380 V, 3-ph., A.C. | Cf. cooling fan for rectifier. |
| Cf. cooling fan<br>for rectifiers. | — | — | — |
| oling fan for brake<br>ances. D.C. motor. | — | Cooling fan for resistances 220/380 V, 3-ph., A.C. | — |

TAB

| | *JNR (Japan) Locomotive ED 46* | *JNR (Japan) Locomotive EF 30* | *JNR (Japan) Train set A* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *Auxiliaries (continued).* | 1 oil pump motor for transformer 440 V, 3-ph., A.C., 60 c/s. | — | 1 oil pump motor for transformer 200 V, 1-ph., A.C., 50 c/s. | 1 oil pump motor for transformer 200 V 1-ph., A.C., 50 c/s. |
| | 1 compressor motor 1 500 V D.C. | 1 compressor motor 1 500 V D.C. | 1 compressor motor 1 500 V D.C. | 1 compressor motor 1 500 V D.C. |
| | 1 miniature compressor 80 V (on 100 V battery). | Same as in col. 2. | Same as in col. 2. | Same as in col. 2. |
| | — | — | 1 pump motor for rectifier cooling 100 V D.C. | — |
| | Control current 100 V D.C. + 100 V A.C. | Control current 100 V D.C. | Control current 100 V D.C. + 100 V A.C. | Control current 100 V D.C. |
| | Battery charging 100 V D.C. | Battery charging 100 V D.C. | Battery charging 100 V D.C. | Battery charging 100 V D.C. |
| | Lighting 100 V D.C. | Lighting 100 V D.C. | Lighting 100 V D.C. | Lighting 100 V D.C |
| | Train heating 1 500 V A.C., 50 or 60 c/s. | — | Heating 1 500 V D.C. | Heating 1 500 V D.C |
| | Cab heating 1 500 V D.C. or A.C. | Cab heating 1 500 V D.C. | Cab heating 1 500 V D.C. | Cab heating 1 500 V D.C. |
| | Ignition device for rectifiers : 440 V, 3-ph., A.C., 60 c/s; 440 V, 1-ph., A.C., 50 c/s; 100 V D.C. | — | — | Ignition device for rectifiers : 69 V, 1-ph., A.C., 50 c/s. |
| *Total power of auxiliaries.* | 69 kW | 60 kW | 25 kW | 11 and 22 kW respectively (?). |
| *Operations to be carried out by hand.* | When changing from A.C. to D.C. or vice versa, controller to zero, hand selector switch reversed. | When changing from A.C. to D.C. or vice versa, controller to zero, hand selector switch reversed. | When changing from A.C. to D.C. or vice versa, controller to zero, hand selector switch to zero. After passing neutral section, hand switch to new position. | When changing fro A.C. to D.C. or vic versa, controller t zero, hand selecto switch to zero. Aft passing neutral sectio hand switch to ne position. |

*tinued).*

| *DB (Germany)*<br>*Locomotive E 320* | *NS/SNCB (Benelux)*<br>*Train sets* | *NS/CFF (TEE)*<br>*Train sets* | *BR (Britain)*<br>*Train sets* |
|---|---|---|---|
| l oil pump motor for transformer. | — | 1 oil pump motor for transformer 220/380 V, 3-ph., A.C. | 1 oil pump motor for transformer 240 V, 1-ph., A.C., 50 c/s. |
| compressor motor D.C. motor. | 1 compressor combined with motor-generator. | Compressor motor 220/380 V, 3-ph., A.C. | 1 compressor motor 110 V D.C. |
| iniature compressor 100 V D.C. | 1 miniature compressor 100 V D.C. | 1 miniature compressor 100 V D.C. | 1 miniature compressor 110 V D.C. |
| — | — | — | — |
| rol current 100 V D.C. Protective devices -ph., A.C., 50 c/s. | Control current 100 V D.C. Kitchen 100 V D.C. | Control current 100 V D.C. Kitchen 220/380 V, 3-ph., A.C. | Control current 100 V D.C. |
| Battery charging 100 V D.C. | Battery charging 100 V D.C. | Battery charging 100 V D.C. | Battery charging 110 V D.C. |
| ghting 100 V D.C. | Lighting 220 V, 100 c/s. | Lighting 220 V, 50 c/s. | Lighting 110 V D.C. |
| Train heating 00 V and 1 500 V. | Train heating 1 500 V and 3 000 V. | Train heating and air-conditioning 220/380 V, 3-ph., A.C. | Train heating 240 V, 1-ph., A.C., 50 c/s. |
| heating 250 V, 1-ph., C., 16. ⅔ or 50 c/s. | Cab heating linked with train heating. | Cab heating 220 V A.C. | Cab heating 240 V, 1-ph., A.C., 50 c/s. |
| — | — | — | — |
| 80 kVA | 34 kW (incl. kitchen). | 275 kVA (incl. kitchen, 41.5 kW, and air-conditioning, 96.5 kW). | 50 kW (incl. heating). |
| ntograph lowered, ain circuit breaker ned, selector switch sed. When overhead as been switched over, utral section passed, r pantograph raised, uit breaker closed. | Traction and auxiliaries disconnected, pantograph lowered, selector switch operated, other pantograph raised circuit breaker re-closed. | Traction and auxiliaries disconnected, main circuit breaker opened, pantograph lowered, selector switch operated, other pantograph raised, main circuit breaker closed, traction motors, etc., reconnected (both with neutral section and overhead line switchover). | No manual operation when changing from one-system to another. Controller can remain in running position. |

TABL

| | *JNR (Japan) Locomotive ED 46* | *JNR (Japan) Locomotive EF 30* | *JNR (Japan) Train set A* | *JNR (Japan) Train set B* |
|---|---|---|---|---|
| *Automatic switch-over when taking vehicle into operation.* | Selector switch automatically placed into proper position by A.C. or D.C. voltage relays. | Same as for loco ED 46. | See for loco ED 46 followed by closure of main circuit breaker. | Same as for train set A. |
| *Automatic action after short voltage interruption.* | A.C. or D.C. voltage relay drops, main circuit breaker tripped. | dto. | Same as for loco ED 46. | dto. |
| *Notching up at start.* | Notch by notch on controller. | Notch by notch on controller. Vernier precision control, may or may not be dependent on motor current. | Automatic start with current relay control. | Automatic start with current relay control. |
| *Multiple control.* | — | Two locomotives can be controlled from one cab. | Multiple control possible. | Multiple control possible. |
| *Controllers.* | One controller for A.C. and D.C. Weak field on master controller. | One controller for A.C. and D.C. No weak field. | One controller for A.C. and D.C. Weak field on master controller. | One controller for A.C. and D.C. Weak field on master controller. |

4.2. *Weight.*

The equipment of a motive power unit for more than one system of current *does not entail any major increase in weight.* The increase is smallest in the case of motive power units exclusively equipped for two D.C. voltages.

4.3. *Motor bogies.*

There are, among the motive power units in existence or under construction, designs with two-axled bogies equipped with *two traction motors* as well as designs with a single motor per bogie (« mono-motor bogie »). The *motor suspension* system does not differ from that encountered on motive power units of conventional type.

4.4. *Pantographs.*

The number of *pantographs* to be installed is influenced by the systems of current to be taken into account and such consequential factors as amperage, static application pressure, and vehicle gauge. It

*ntinued).*

| *DB (Germany) Locomotive E 320* | *NS/SNCB (Benelux) Train sets* | *NS/CFF (TEE) Train sets* | *BR (Britain) Train sets* |
|---|---|---|---|
| ? | No automatic action. | Yet to be determined. | No automatic action. |
| Main circuit breaker tripped. | Voltage relay drops, line circuit breakers (traction) tripped, motor-compressor-generator and heating disconnected. | Voltage relay drops, main circuit breaker opened, motor-generator and traction motors stopped. | Voltage relay drops, main circuit breaker opened. |
| ntroller set for desired position, followed by tomatic notching up. | Automatic start, dependent on traction motor current. | Notch by notch on controller. | Automatic start, with current relay control. 3 controller positions : ½ voltage, full voltage, weak field. |
| — | Multiple control possible, also in conjunction with NS train sets. | Multiple control possible; maximum two train sets. | Multiple control possible. |
| controller, weak field n master controller. | One controller, weak field on master controller. | A.C. and D.C. one controller, weak field on master controller. | One controller, weak field on master controller. |

is possible to design a four-system motive power unit with but three pantographs (NS/CFF project).

Where the vehicle gauge does not give rise to difficulties, it is possible to use the same pantograph for A.C. as well as D.C. (cf. JNR, and pantograph No. 2 of the NS/CFF project).

Such a solution calls for a compromise as regards the static application pressure, the number of bows, the number of friction strips per bow, and the material used for these strips. Where there are differences in the admissible maximum stagger of the contact wire (without catenary), this need not give rise to difficulties as the stagger can always be limited automatically.

4.5. *System selection devices.*

As far as the system *selection devices* and the method of their operation (manual or automatic) is concerned, opinions are apt to differ, partly due to different operating conditions. Except in the case of *British Railways,* the different designs

generally provide for the selection and switchover devices to be manually operated by one or more switches installed in the driving cab.

The pantograph change is generally controlled by means of one or more separate hand-operated switches which are in any case indispensable so as to permit the lowering of the pantographs as an independent action, e.g. in an emergency.

With British Railways, where the same pantograph is used all the time, the reconnection of the transformer primary windings is carried out automatically by magnetic apparatus located by the line side.

In general, the connections are arranged in such a way that the main circuit breaker is tripped whenever the system of current differs from the one pre-selected. Several administrations take this protection against an erroneous choice of system a step further by preventing the closure of the main circuit breaker when the system of current does not agree with the one selected. It is also possible to prevent the raising of a pantograph which does not belong to the pre-selected system; but this can of course only be done if only one pantograph can be used for a given feed voltage.

Mutual interlocking of the pantographs is, of course, desirable. In general, the safety devices are based on the use of voltage relays or, occasionally, frequency relays. These relays always preceed the main circuit breaker(s).

Except in the case of rolling stock designed for several D.C. systems, no changes are made in the *main traction circuit* when changing from one system of current to another. With the Japanese EF 30 locomotive, when running on an A.C. feed, there is a transfer from 3 motors in series to 2 motors in series (instead of 3 motors in parallel); this is possibly connected with the permissible load on the silicon rectifiers; moreover, this locomotive works on a particular section of line of very short length, with gradients of 1 in 40 (25 °/₀₀).

4.6. *Circuit breakers.*

In the case of a motive power unit exclusively fed with A.C., *a single air-blast circuit breaker,* immediately behind the pantograph(s), is adequate for complete protection.

In the case of multiple-unit trains exclusively designed for running in two D.C. systems, it is possible either to provide a D.C. main circuit breaker or, alternatively, two or more line circuit breakers in series, the protection being mainly ensured by a fuse in each system.

With motive power units designed to work on A.C. as well as D.C., it is usual to provide an A.C. air-blast circuit breaker. With high power ratings (e.g. in the case of the JNR locomotives and the NS/CFF project), provision is also made for a *high-speed circuit breaker* in the D.C. circuit.

Apart from its function as main feed circuit breaker, the A.C. main circuit breaker is also used as a protection against overload on the primary side of the transformer, overloads or back-fire in the rectifier circuit, earth leakage on the secondary side of the transformer, low voltage, erroneous choice of system, and overload on the tertiary windings (if any) for auxiliaries.

Similarly, the high-speed D.C. circuit breaker serves, not only as main feed circuit breaker when working on D.C. feed, but also as a protection against overload in the D.C. circuit, low feed voltage and erroneous choice of system.

If, with D.C. feed, the A.C. circuit breaker remains connected, the function of the high-speed D.C. circuit breaker can be confined to ensuring the disconnection in the case of overload in the D.C. circuit (JNR). In that case, the A.C. main circuit breaker must be able to pass the considerable current encountered with direct D.C. feed.

4.7. *Over-voltage protection.*

With A.C. feed, it is usual to provide, as over-voltage protection, a voltage-controlled resistance with spark gap.

With D.C. feed, a condenser type protection is usually resorted to.

4.8. *Transformer design.*

Normally, the transformer is equipped with forced cooling, with a pump for oil circulation and a fan supplying cool air for a radiator. As an exception, the Japanese EF 30 locomotive is equipped with a transformer without oil pump, relying on natural cooling, possibly because of the special character of this locomotive.

In most cases, measures have been taken to reduce the weight and volume of the transformer.

The DB locomotive, which is exclusively fed by A.C., is equipped with *transformer regulation,* the regulation taking place on the primary side. The moving contact used for this purpose is limited to step 39 at 15 kV, 33 at 20 kV, and 27 at 25 kV so that a feed selection system is obtained at the same time. This arrangement entails, of course, a smaller number of regulating steps with the higher feed voltages.

With the rolling stock of British Railways, which is exclusively fed by single-phase A.C., the regulation takes place on the secondary side of the transformer, the number of steps available for regulation being the same on both systems.

4.9. *Traction motors.*

With all motive power units, designed for D.C. as well as A.C., the feed voltage of the traction motors is regulated by means of starting resistances in the D.C. circuit; the same resistances may also be used for electric braking.

With the rolling stock exclusively fed by A.C. (DB and BR), the traction motors are permanently connected in parallel. With rolling stock designed to work with D.C. as well, it is usual to resort to series and series-parallel connections, or series-parallel and parallel connections. The change-over from one connection to another is carried out at higher powers by the short-circuit method, and at lower powers by the bridge circuit method.

With the exception of the Japanese EF 30 locomotive, the speed is regulated, with all types of motive power units, by weakening the field of the traction motors, either by tapping the field windings or by using resistances in conjunction with inductive shunts.

4.10. *Rectifiers.*

As regards the types of rectifiers used, certain differences are encountered.

Where mercury vapour rectifiers are used, however, they are always of the single-anode type, the excitrons being air-cooled and the ignitrons water-cooled. With the latest designs (JNR, DB and NS/CFF), silicon rectifiers are provided.

The connection schemes adopted for the rectifier sets are apparent from the attached circuit diagrams. Here, too, a relatively great number of different solutions are encountered.

The DB locomotive, being the only one where such a solution is possible, has an independent secondary transformer winding, with bridge-connected rectifier set, for each traction motor.

In contrast, the tentative design for the NS/CFF train provides for a single bridge-connected rectifier set for the entire D.C. circuit. The JNR make use of the simple bridge connection as well as of full wave rectification with intermediate transformer tapping (push-pull connection), a solution also adopted by British Railways. On the Japanese EF 30 locomotive, which is equipped with silicon rectifiers, there are two series-connected bridges with two corresponding secondary transformer windings.

The mercury vapour rectifiers have the well-known advantage of a high overload capacity which is, in principle, absent in the case of silicon rectifiers.

The auxiliary power required for the silicon rectifiers is considerably lower than that required for the mercury vapour types. The weight/power ratios (kg/kW) are also lower with silicon rectifiers.

In all cases, *smoothing coils* are used in order to reduce the ripple voltage occurring in the D.C. circuit. The undulation

coefficient behind the coil amounts to approx. 20 % (with British Railways 30 %).

The D.C. series motors with single armature and single commutator generally used as traction motors are provided with laminated main poles and double or treble brushes. In addition, the Japanese Railways also have motors where even the commutation poles are laminated. British Railways use foliated commutation poles on all their motors. The stators are normally not foliated. Although the Japanese Railways with an undulation coefficient of 20 % and British Railways with one of 30 % do not regard the shunting of the main poles as necessary, the German Federal Railways shunt the main poles permanently at 4 %.

4.11. *Auxiliaries.*

All the multi-current motive power units are equipped with a motor-generator set for the feed of the auxiliaries.

With the units designed for two D.C. voltages, this set is equipped with two motors which are series-connected (3 000 V) or parallel-connected (1 500 V).

On the DB locomotive, designed for A.C. supply only, the motor of the set is fed by single-phase A.C., taken from a tertiary winding of the main transformer.

With all the motive power units which are able to run on 1 500 V D.C., the motor-generator sets are fed by 1 500 V D.C., either directly, or through transformer and rectifier.

In many cases, the same applies to the feed of the compressor motors.

As regards the feed of transformer and rectifier, different solutions are encountered, e.g. by means of a main secondary winding and main (traction) rectifier set (as with the NS/CFF project), or by means of a separate (tertiary) winding and separate rectifier (DB and JNR).

In general, miniature compressors, operating current battery charging and train lighting are fed by the motor-generator set.

Auxiliaries which are exclusively needed for A.C. feed (such as transformer oil pump, rectifier fans) are either fed by the motor-generator set or from a tertiary winding of the main transformer (without rectifier).

Auxiliaries which are used with A.C. as well as D.C. feed (such as traction motor blowers and resistances) are either fed in the same way as the motor-generator set, or *by* that set.

The rolling stock of British Railways is not equipped with motor-generator set, but most of the auxiliaries are fed from a tertiary winding of the transformer; the remainder are fed by the battery which is charged by a special installation with A.C. input.

The trains heating circuit is generally fed either directly (with D.C. feed) or after transformation (tertiary winding), possibly with rectification.

Only the NS/CFF project makes use, for the integrated multiple-unit train, of a motor-generator set for the current supply to the heating and air-conditioning system; this choice has been prompted by the fact that these train sets are intended to run in conjunction with pre-existing vehicles.

In contrast to the statements made above, and no doubt due to special operating conditions, the train heating system of the Japanese ED 46 locomotive is fed, even with 1 500 V D.C. feed, by 1 500 V A.C. which is, in this case, obtained through rectifier inversion.

## 5. GENERAL CONSIDERATIONS.

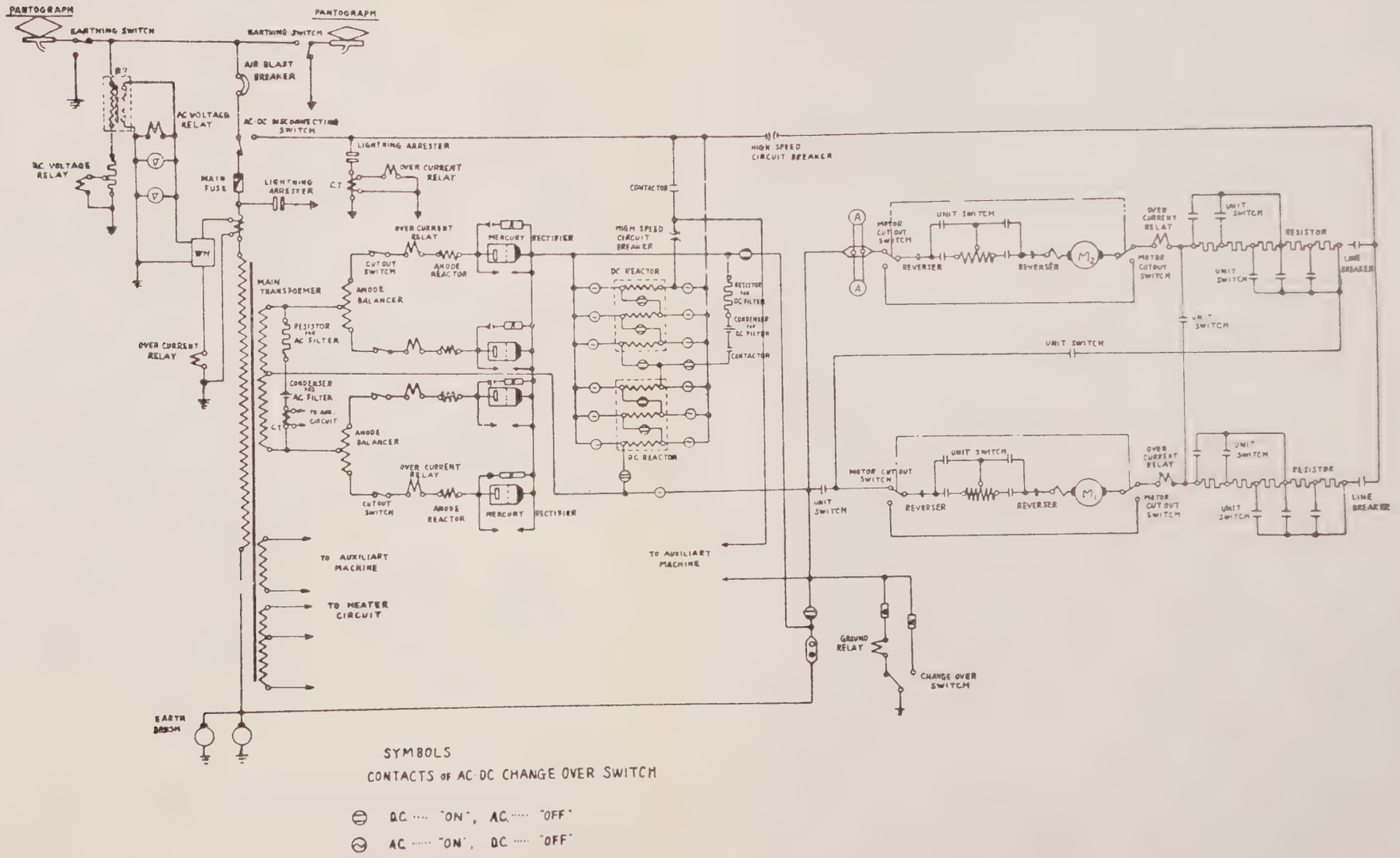
The general summaries will be embodied in a special report which will be compiled jointly with the reporter dealing with the administrations corresponding in the French language.

Since, in the countries corresponding in the English language, the polycurrent motive power units in existence or under construction were found to be spread over four categories, it has not been possible to draw any further conclusions than those outlined in the body of this report.

In conclusion, I should like to express my sincere thanks to those who have been good enough to forward their replies and those who have collated them for me.

## JAPANESE NATIONAL RAILWAYS.

**Schematic diagram of main circuit and rectifier circuit of A.C.-D.C. dual purpose electric locomotive ED 461.**




SYMBOLS

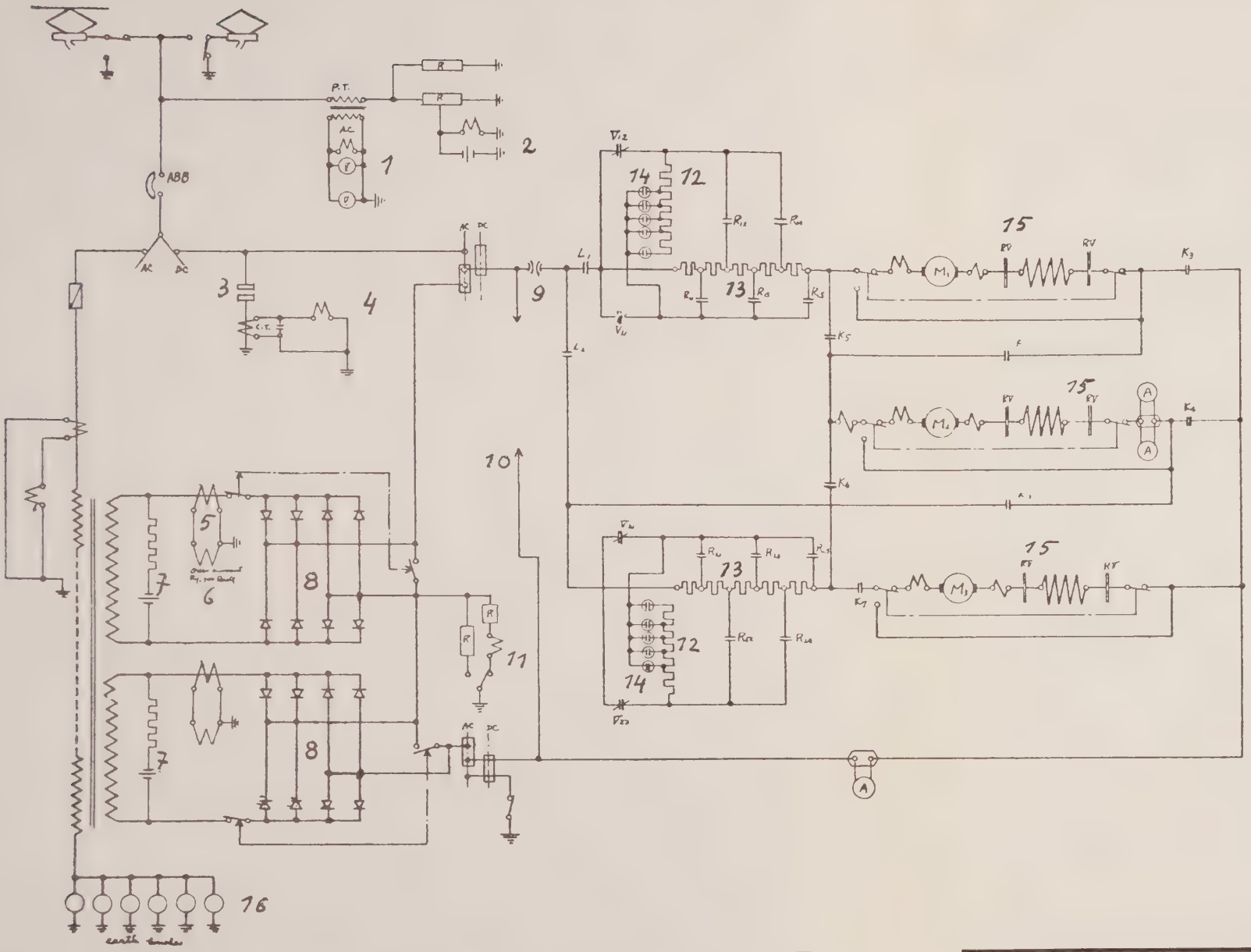
CONTACTS OF AC-DC CHANGE OVER SWITCH

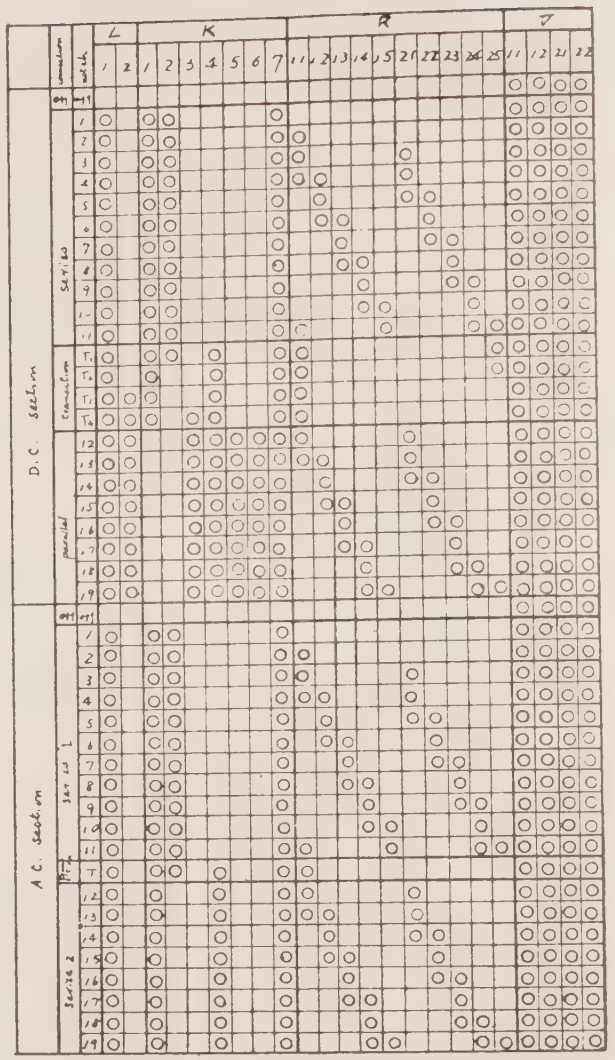
⊖ D.C. ···· "ON", A.C. ···· "OFF"

⊜ A.C. ···· "ON", D.C. ···· "OFF"

## JAPANESE NATIONAL RAILWAYS.

**Schematic diagram of main circuit of A.C.-D.C. dual purpose electric locomotive EF 301.**



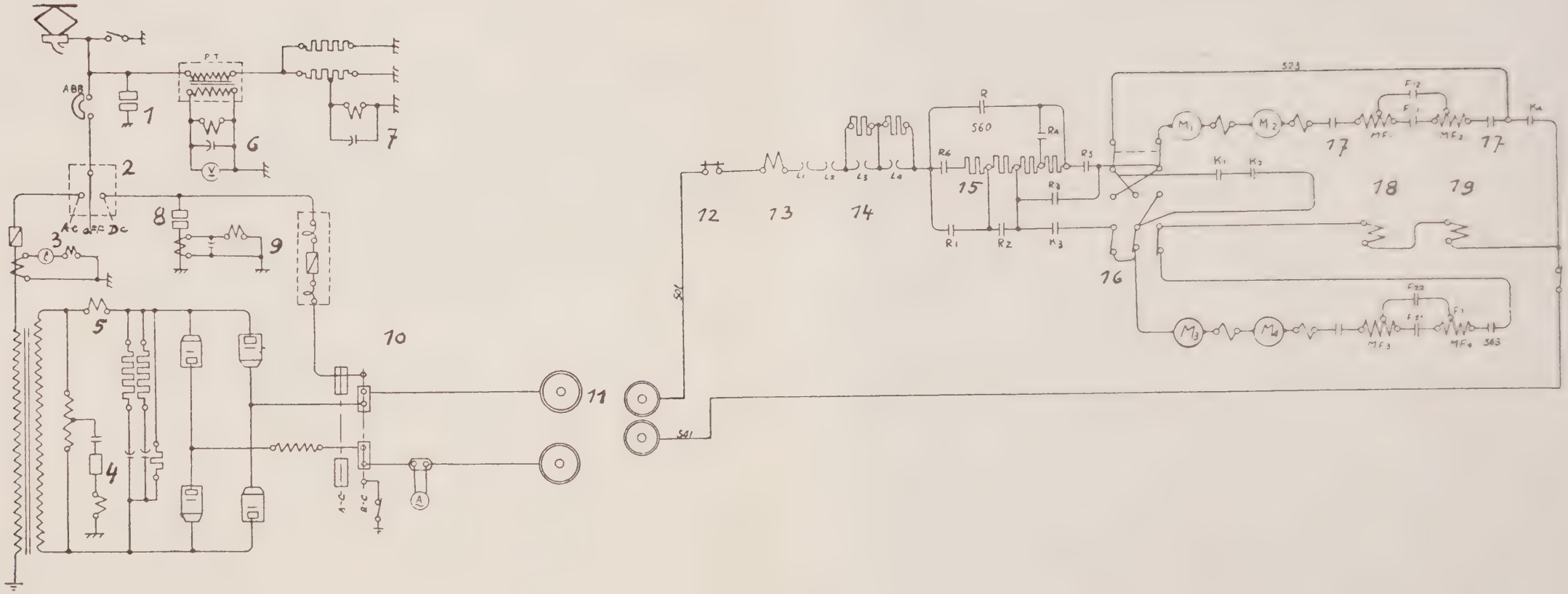




| Position | LEGEND. |
|---|---|
| 1 | A.C. voltage relay. |
| 2 | D.C. voltage relay. |
| 3 | Surge suppressor. |
| 4 | Protecting relay. |
| 5 | Current transformer for over current relay for rectifier. |
| 6 | Over current relay. |
| 7 | A. C. filter. |
| 8 | Silicon rectifiers. |

| Position | LEGEND. |
|---|---|
| 9 | High speed circuit breaker. |
| 10 | To auxiliary circuits. |
| 11 | Earth relay. |
| 12 | Vernier resistors. |
| 13 | Main resistors. |
| 14 | Cam switches for vernier resistor. |
| 15 | Reverser. |
| 16 | Earth brushes. |

## JAPANESE NATIONAL RAILWAYS.

**Schematic diagram of main circuit and rectifier circuit of A.C.-D.C. dual purpose electric railcar A type.**

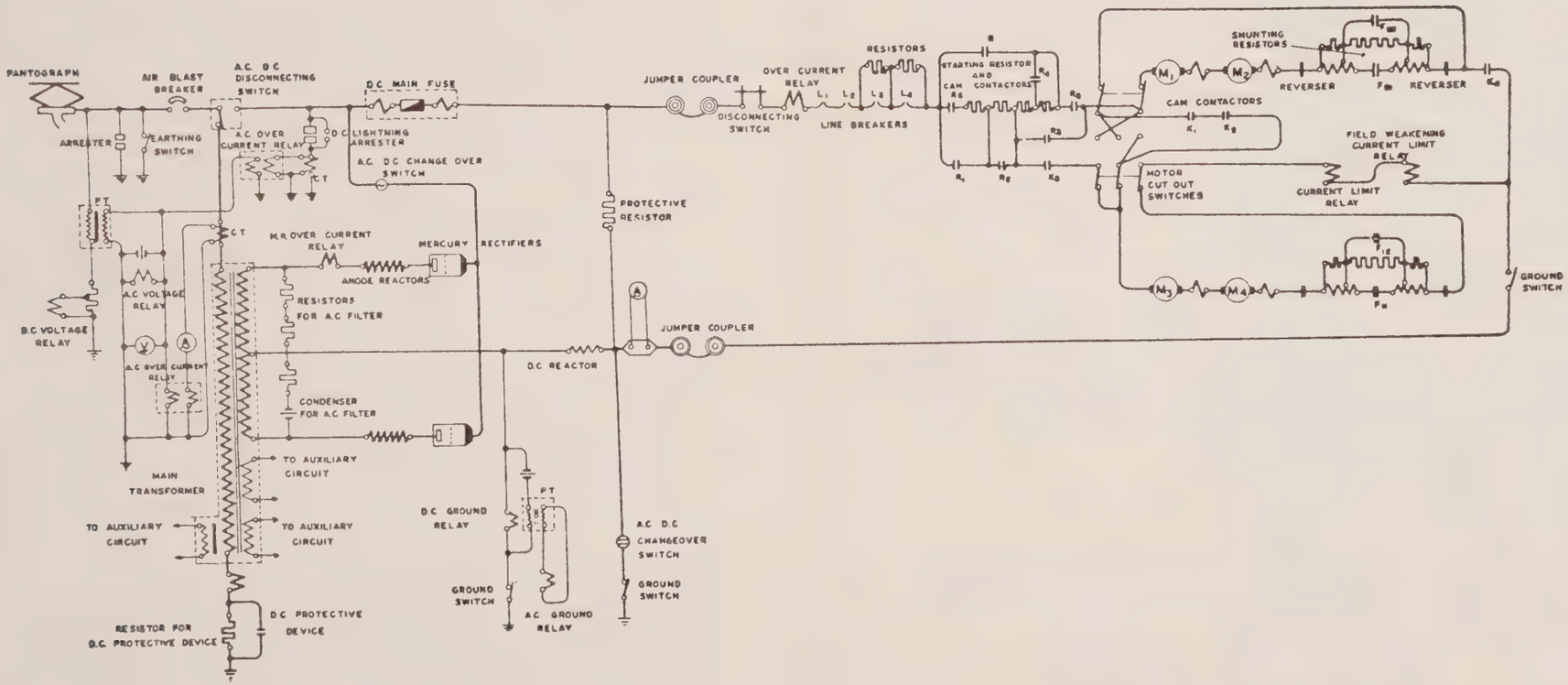



| Position. | LEGEND. |
|---|---|
| 1. | A.C. lightning arrester. |
| 2. | A.C.-D.C. commutator. |
| 3. | Ammeter and A.C. overload relay. |
| 4. | Earth relay. |
| 5. | Overload relay. |
| 6. | A.C. voltage relay. |
| 7. | D.C. voltage relay. |
| 8. | D.C. lightning arrester. |
| 9. | Protective relay. |
| 10. | A.C.-D.C. commutator. |

| Position. | LEGEND. |
|---|---|
| 11. | Coupler. |
| 12. | Section switch. |
| 13. | Overload relay. |
| 14. | Line circuit breaker. |
| 15. | Starting resistance. |
| 16. | Cut-out switch for traction motors. |
| 17. | Inverser. |
| 18. | Current limit relay. |
| 19. | Limit relay for field weakening. |
| 20. | A.C. filter. |

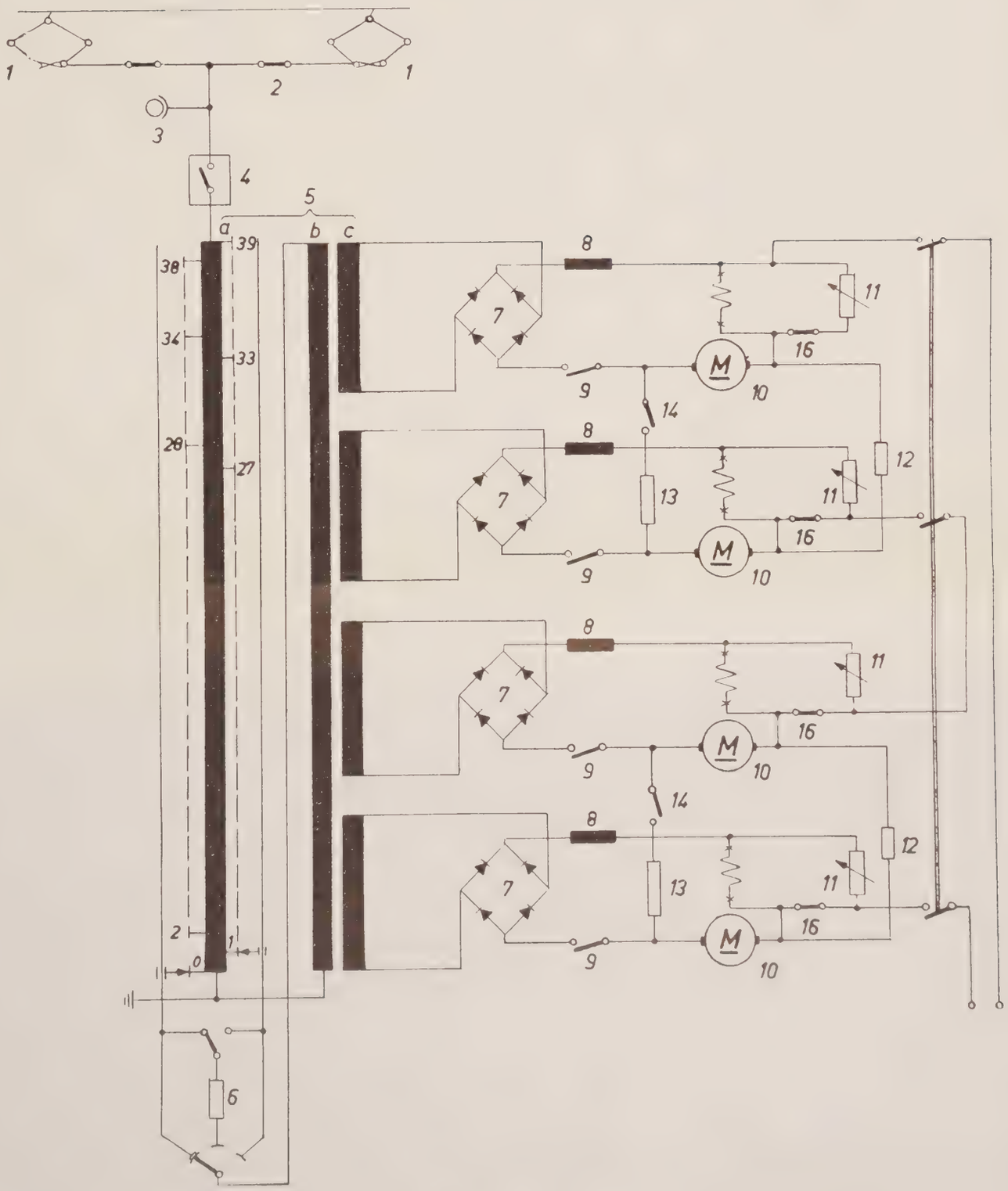
## JAPANESE NATIONAL RAILWAYS.

Schematic diagram of main circuit and rectifier of A.C.-D.C. dual purpose electric railcar type B.



## DEUTSCHE BUNDESBAHN.

**Dual frequency locomotive, type E 320. Basic diagram.**

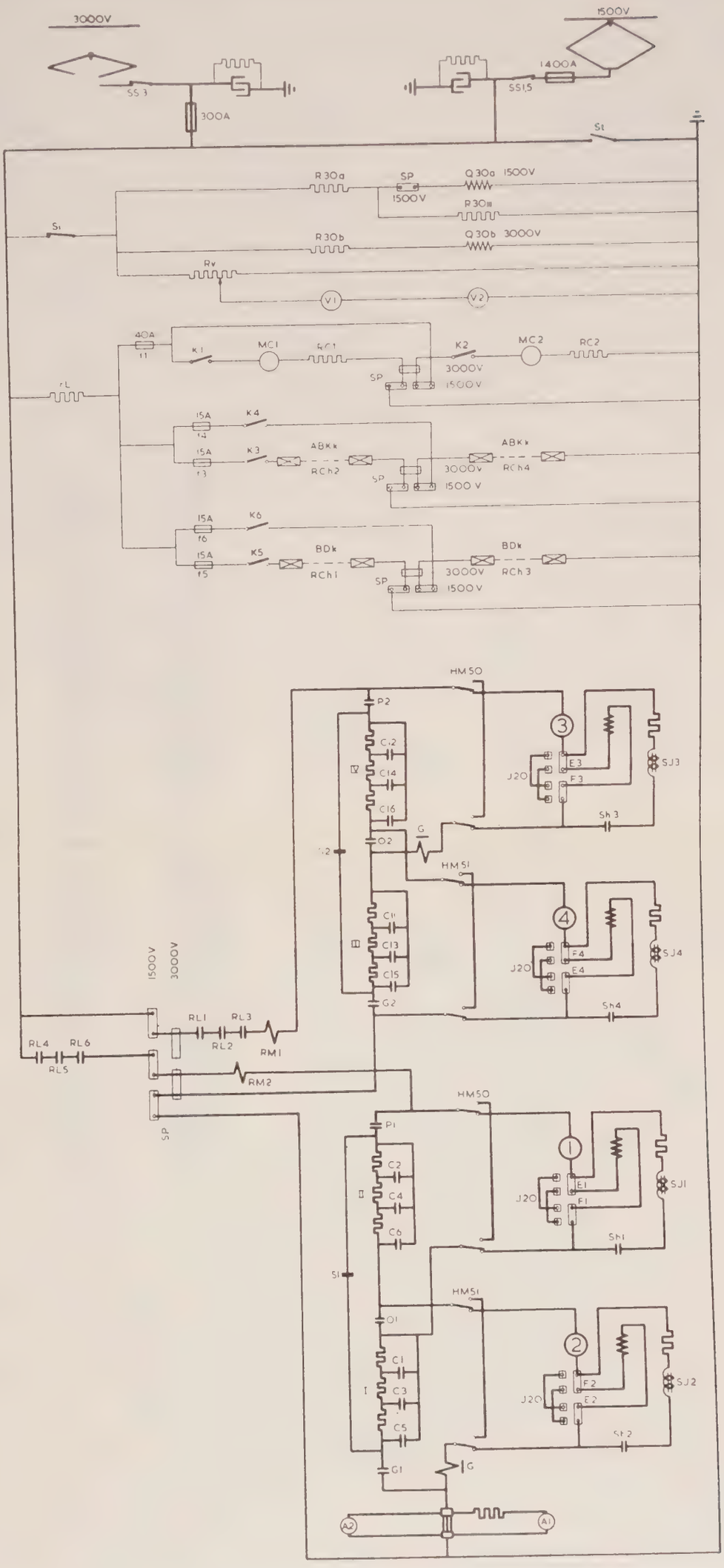



LEGEND.

1. Pantograph.
2. Roof line disconnection switch.
3. H.T. transformer.
4. Main circuit breaker.
5. Transformer with graduator :
   a) regulating winding;
   b) H.T. winding;
   c) L.T. winding.
6. Power circuit breaker with change over resistance.
7. Rectifier.
8. Smoothing coil.
9. Cut-out contactor.
10. Traction motor.
11. Field weakening device.
12. Compound resistance.
13. Braking resistance.
14. Braking contactor.
15. Exciter contactor.
16. Contact at field weakening control device.

## NETHERLANDS RAILWAYS/BELGIAN NATIONAL RAILWAYS.

**Double « Benelux » multiple unit set. — H.T. circuit diagram.**

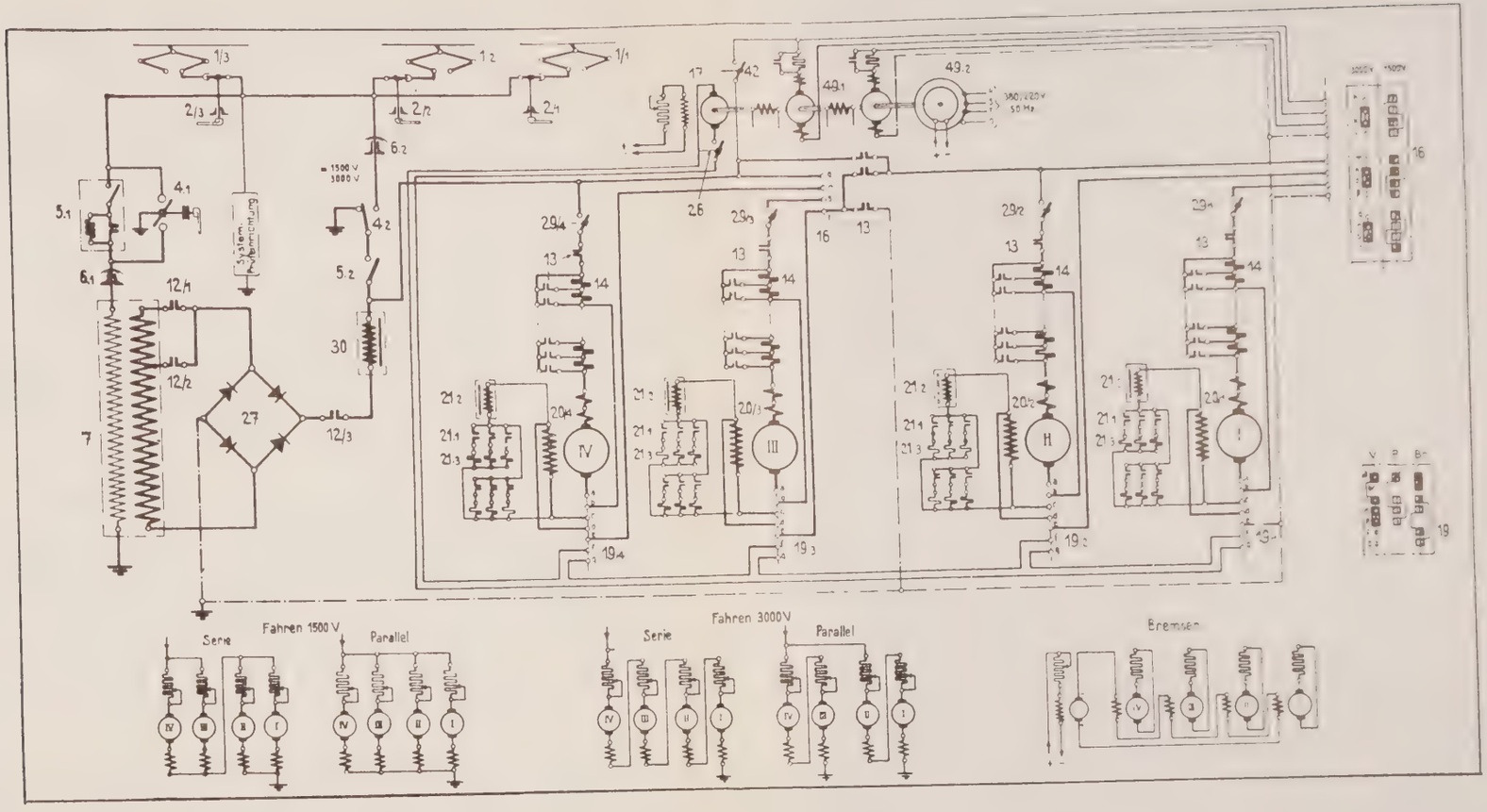



LEGEND.

| | |
|---|---|
| Q 30 : | Voltage relay. |
| M.C. : | Motor-compressor set. |
| R.Ch. : | Resistance for compartment heating. |
| S.J. : | Inductive shunt. |
| R.I., 1 to 6 : | Line circuit breaker contactors. |
| R.M. : | Overload relay. |
| G. : | Acceleration relay. |

## SWISS FEDERAL RAILWAYS/NETHERLANDS RAILWAYS.

### T.E.E. polycurrent multiple unit sets. Basic diagram.




Explanation of German terms :

System Prüfeinrichtung = checking device for the system. — Fahren = traction. — Bremsen = braking.

LEGEND.

| Position. | Quantity. | LEGEND. |
|---|---|---|
| 1/1 | 1 | Pantograph 15 kV, 16 2/3 c/s (SBB).<br>Pantograph 25 kV, 50 c/s (SNCF/CFL).<br>Pantograph 3 000 V, D.C. (FS). |
| 1/2 | 1 | Pantograph 15 kV, 16 2/3 c/s (DB/öBB). |
| 1/3 | 1 | Pantograph 3 000 V D.C. (SNCB/CFL).<br>Pantograph 1 500 V D.C. (NS/SNCF). |
| 2 | 4 | Section switches. |
| 4.1 | 1 | Earth switch. |
| 4.2 | 1 | System switch. |
| 5.1 | 1 | Air blast circuit breaker (A.C.). |
| 5.2 | 1 | High-speed circuit breaker (D.C.). |
| 6.1 | 1 | H.T. inlet (15 kV, 16 2/3 c/s, 25 kV, 50 c/s). |
| 6.2 | 1 | H.T. inlet (3 000 V and 1 500 V D.C.). |
| 7 | 1 | Main transformer. |
| 12/3 | 1 | Cut-off contactor for position 27. |
| 12/1 | 1 | Traction contactor for 15 kV, 16 2/3 c/s. |

| Position. | Quantity. | LEGEND : |
|---|---|---|
| 12/2 | 1 | Traction contactor for 25 kV, 50 c/s. |
| 13 | 1 | D.C. cam contactor gear. |
| 14 | 1 | Starting and braking resistance. |
| 16 | 1 | System commutator. |
| 17 | 1 | Brake generator. |
| 19 | 4 | Inverter and braking switches. |
| 20 | 4 | Traction motors. |
| 21.1 | 12 | Field weakening contactors. |
| 21.2 | 3 | Inductive shunts for field weakening. |
| 21.3 | 1 | Field weakening resistance. |
| 26 | 1 | Brake exciter contactor. |
| 27 | 1 | Traction rectifier. |
| 29 | 4 | Motor cut-out contactors. |
| 30 | 1 | Smoothing coil. |
| 42 | 1 | Switch for auxiliaries. |
| 49.1 | 1 | Motor for three-phase generator. |
| 49.2 | 1 | Three-phase generator for auxiliaries. |

[ 621 .335 ]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

ENLARGED MEETING OF THE PERMANENT COMMISSION
(NEW DELHI. 1959).

**QUESTION 2.**

# Problems met in the design of multi-current rolling stock. Existing types : experimental results. Future developments.

## REPORT

*(Austria, Belgium and Belgian Congo, Bulgaria, Cambodia, Czechoslovakia, Denmark, Ethiopia, Finland, France and French Union, Greece, Hungary, Italy, Lebanon, Luxemburg, Poland, Portugal and Overseas Territories, Rumania, Siam, Spain, Switzerland, Syria, Turkey, Viet-Nam and Yugoslavia),*

by K. von Meyenburg,

Ingénieur. Premier Chef de Section de la Division de la Traction et des Ateliers, Chemins de fer fédéraux suisses, Berne.

### I. INTRODUCTION.

The present report deals with the problems raised when designing locomotives, motor coaches and electric rail motor sets which can run on at least two different voltages or types of current. It is based on information received from Austria (OeBB), Belgium (SNCB), France (SNCF), Italy (FS) and Switzerland (CFF). In these countries, a certain number of multi-current units have been put into service between 1955 and 1958, and others are under construction at the present time. There are several reasons for this :

— running trains without change of locomotive over the different supply systems of a single administration;

— motor train sets in international service running over lines belonging to several administrations who use different supply systems;

— shunting in transition stations where the stock can pass from lines electrified on one system to lines electrified on a different system.

The polycurrent motor units now in service are listed in Table 1 and those under construction in Table 2. The user of these vehicles is shown in diagram form in Table 3.

### II. GENERAL.

From the point of view of the different supply systems used, multi-current units can be divided into three categories :

*a*) those supplied merely with different voltages of D.C.;

TABLE 1. — MULTI-CURRENT MOTI

| | *Category* a D.C. - D.C. | | | | | | | | *Categor* A |
|---|---|---|---|---|---|---|---|---|---|
| *Administration* | *S.N.C.B.* « Benelux » | | *Oe.B.B.* | | *C.F.F.* | | *C.F.F.* | | |
| *Type designation and numbers* | 220901/04 | | E 1051.01 | | Ee 3/3II 16501/02 | | Ee 3/3II 16503/0 | | |
| *Current supply systems* | 1500 V | 3000 V | 15 kV 16 2/3 c/s | 20 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/ | |
| *Type of vehicle* | Multiple-unit train | | Locomotive | | Locomotive | | Locomotive | | |
| *First year of operation* | 1957 | | 1957 | | 1957 | | 1957 | | |
| *Number of vehicles* | 4 (plus 8 of NS) | | 1 | | 2 | | 2 | | |
| *Utilisation* | Express trains | | Express and goods trains | | Shunting | | Shunting | | |
| *Lines on which vehicles are used* | Brussels-Amsterdam | | Vienna-Passau | | Basle | | Basle | | |
| *Maximum speed* . . .(km/h) | 125 | | 110 | | 45 | | 45 | | |
| *Power at one hour rating* (HP) | 1 000 | | 2 800 | | 690 | | 735 | | |
| *at a speed of* . . .(km/h) | 75.5 | | 82.0 | | 26.5 | | 27.0 | | |
| *Manufacturers of electr. parts* | — | | ELIN | | BBC | | MFO | | |
| *Axle arrangement* | 2'Bo' + Bo'2' | | Bo'Bo' | | C | | C | | |

TABLE 2. — MULTI-CURRENT MOTI

| | *Categ.* a D.C.-D.C. | *Category* b A.C. - A.C. | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Administration* | | *S.N.C.F.* (1) | | *S.N.C.F.* | | *S.N.C.F.* | | |
| *Type designation and numbers* | None | C 30101/09 | | BB 16500 | | BB 20004/05 | | |
| *Current supply systems* | | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 3 000 V | 25 kV 50 c/ |
| *Type of vehicle* | | Locomotive | | Locomotive | | Locomotive | | |
| *Number of vehicles* | | 9 | | 1 | | 2 | | |
| *Utilisation* | | Transfer of goods trains | | Passenger and goods trains | | Passenger and goods trains | | |
| *Lines on which vehicles are used* | | St-Louis - Basle - Muttenz | | S.N.C.F. 25 kV and 1 500 V lines | | S.N.C.F., S.N.C.B. and N.S 25 kV, 50 c/s, 1 500 V/3 000 V lines | | |
| *Maximum spped* . .(km/h) | | 45 | | 90/150 (2) | | 100/140 (2) | | |
| *Power at one-hour rating* (HP) | | 690 | | 3 500 | | 2 970 | | |
| *at a speed of* . . .(km/h) | | 26.5 | | 47.0/87.0 (2) | | 45.5/68.0 (2) | | |
| *Manufacturers of electr. parts* | | SAAS | | | | | | |
| *Axle arrangement* | | C | | B'B' | | B'B' | | |

(1) Locomotives similar to C.F.F. locomotives Ee 3/3II 16505/06.

## ER UNITS AT PRESENT IN OPERATION

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | *Category* c<br>*D.C. - A.C.* | | | | | | | | |
| *C.F.F.*<br>e3/3II 16505/06 | | | *S.N.C.F.*<br>BB 30001/02 | | *S.N.C.F.*<br>BB 30003/04 | | | *F.S.*<br>Ale 840 | | *S.N.C.F.*<br>CC 250001/09 | | | | | | | | | | |
| 5 kV<br>2/3 c/s | 25 kV<br>50 c/s | | 15 kV<br>16 2/3 c/s | 25 kV<br>50 c/s | 15 kV<br>16 2/3 c/s | 25 kV<br>50 c/s | | 3 000 V | 3600 V Δ<br>16 2/3 c/s | | 1 500 V | 25 kV<br>50 c/s | | | | | | | |
| Locomotive<br>1958<br>2<br>Shunting<br><br>Basle | | | Locomotive<br>1958<br>2<br>Express trains<br><br>Basle-Luxemburg | | Locomotive<br>1958<br>2<br>Express trains<br><br>Basle-Luxemburg | | | Multiple-unit train<br>1957<br>24<br>Passenger trains<br><br>Milan-Genoa-Ventimiglia, Turin-Bologna and Turin-Rome | | | Locomotive<br>1955<br>9<br>Passenger and goods trains<br><br>Savoy network | | | | | | | | | |
| 45<br>690<br>26.4<br>SAAS<br>C | | | 160<br>4 460<br>85.7<br>MFO<br>Bo′Bo′ | | 160<br>4 040<br>74.5<br>BBC<br>B′B′ | | 5 120<br>94.5 | 150<br>880<br>70.0<br>CGE and TIBB<br>2′2′ + Bo′Bo′ | | | 100<br>400<br>11.0<br>MFO<br>Co′Co′ | | 4 200<br>65.0 | | | | | | | |

## ER UNITS UNDER CONSTRUCTION

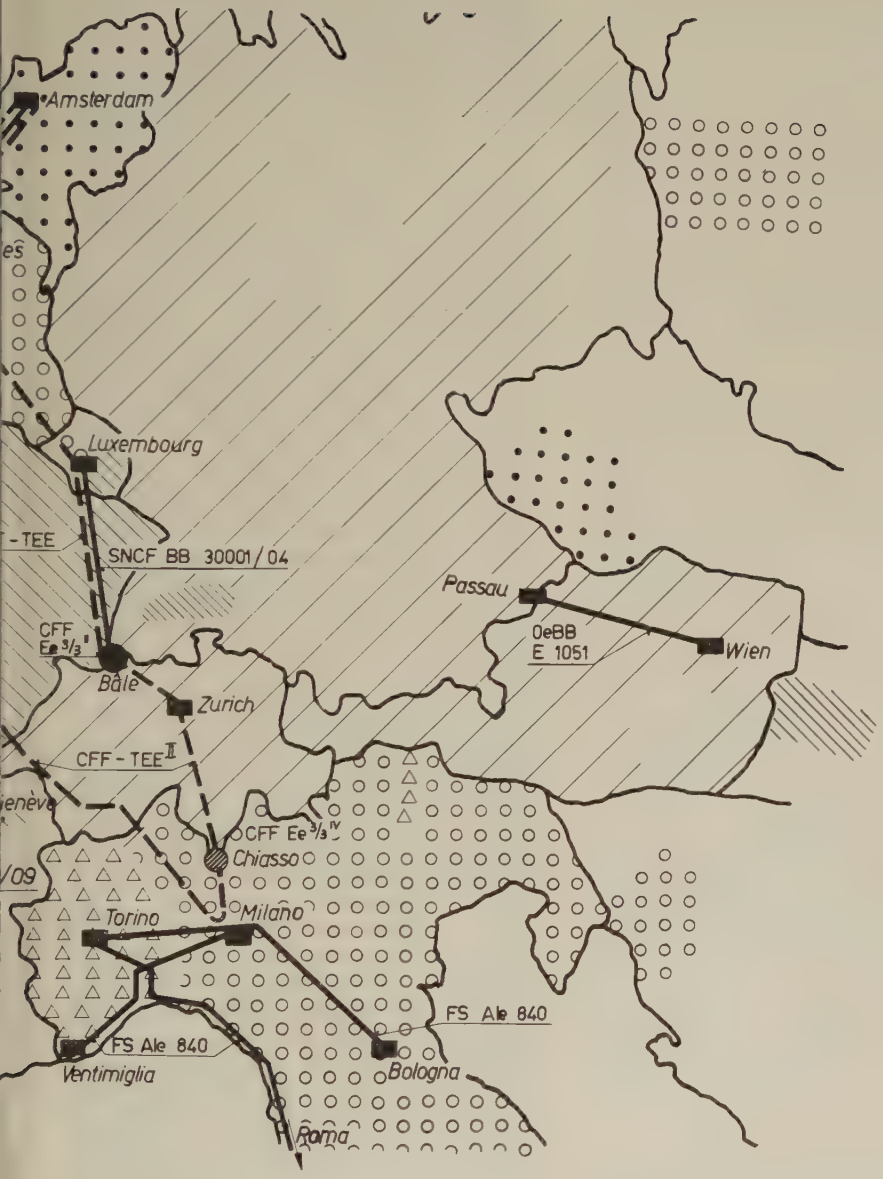
| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | *Category* c<br>*D.C. - A.C.* | | | | | | | | | | | | |
| *C.F.F.*<br>Ae 4/6III 10851 | | | *C.F.F.*<br>TEE II RAe 1051/54 | | | | | *C.F.F.*<br>Ee 3/3IV 16551/60 | | | | | | | | | | | | |
| 00 V | 15 kV<br>16 2/3 c/s | 25 kV<br>50 c/s | 1 500 V | 3 000 V | 15 kV<br>16 2/3 c/s | 25 kV<br>50 c/s | | 1 500 V | 3 000 V | 15 kV<br>16 2/3 c/s | 25 kV<br>50 c/s | | | | | | | | | |
| Locomotive<br>1<br>Goods trains and shunting<br>Geneva area | | | Multiple-unit train<br>4<br>TEE Expresses<br><br>Zurich-Milan-Paris, possibly Zurich-Brussels-Amsterdam-Paris | | | | | Locomotive<br>10<br>Shunting<br><br>Geneva and Chiasso | | | | | | | | | | | | |
| 110<br>2 300<br>83.0<br><br>BBC<br>(I Ao) Bo (Ao I) | | | 160<br>3 000<br>85<br>MFO<br>2′2′ + (A I A)′ (A I A)′ + 2′2′ + 2′2′ + 2′2′ + 2′2′ possible | | 3 000<br>85 | 3 150<br>88 | 3 000<br>85 | 60<br>520<br>23.8<br><br>SAAS<br>C | | | | | | | | | | | | |

Two reduction ratios.

CC 3000 V
CC 1500 V
CA 15000 V 16 2/3 Hz
CA 20000 V 50 Hz
CA 25000 V 50 Hz
CA 3600 V Δ 16 2/3 Hz
engins de ligne en service
engins de ligne en construction
loc de manoeuvres en service
loc de manoeuvres en construction
SNC
BB
Paris

*Legend :*

CC = D.C.
CA = A.C.
Hz = c/s




e power units in operation (main line).
e power units under construction (main line).
ng locomotives in operation.
ng locomotives under construction.

*b*) those supplied merely with different voltages and frequencies of A.C.;

*c*) those supplied with both D.C. and A.C. (single or three phase).

At the present time, in each of these three categories, the existing multi-current units can only run on two different systems. Units which can run on three or four systems are however under construction.

The chief technical data about the units in service and as full details as possible about the units under construction are given in Table 4.

This table shows very clearly the widespread differences between these units, both as regards their user and their technical design. The problems raised by the designing of polycurrent vehicles are influenced on the one hand by the use to which they will be put, and on the other by the differences between the supply systems. Most of the problems of use are the same as those occurring with monocurrent units. The problems due to the different supply systems are the following:

— picking up the current;
— selecting the system of current;
— cutting off the current (protection);
— supplying the traction motors and regulating the speed;
— design of the traction motors;
— the electric brake, if one is fitted;
— supplying the auxiliary equipment;
— heating and lighting the train;
— controls.

In principle, therefore, it is a question of electrical problems; those in connection with the mechanical part of these vehicles can be left aside in the present report.

## III. ELECTRICAL PART.

### A. Picking up the current.

All the polycurrent units are supplied from an overhead line; the third rail therefore is not used. The pantographs of these vehicles are shown in Table 5. This table shows that the number or type of the pantographs fitted cannot be directly related to the number or systems of the supply current used by these units. Some of them have one or two pantographs per supply system and others one alone. The first case does not give rise to any special difficulties, provided there is sufficient space on the roof of the vehicle. At times this is the only practical solution, as in the case of the Ale sets of the Italian State Railways which can run on 3 000 V D.C. (single pole catenary) or 3 600 V three phase current (bi-pole catenary). The use of a single pantograph or single type of pantograph is the usual practice in the case of shunting locomotives.

The technical characteristics of the various pantographs are shown in Table 6, which brings out very clearly the diversity of the pantographs used. This is due to the fact that the various administrations do not make use of the same types of catenary, nor of the same materials for the rubbing strips.

The construction of the catenary is essentially influenced by the clear construction gauge and the voltage of the current. The question of the gauge is dealt with at the present time by ORE ([1]). It is clear that in Europe only two widths of bow need be considered, provided that in certain countries side horns made of insulating material are used.

The standardisation of the materials used for the rubbing strips has not yet been the subject of study on the international plane. At the present time, the question of the pantograph has to be gone into whenever a new type of polycurrent unit is put into service. At the present time, the most interesting case is that of the multi-current TEE sets of the Swiss Federal Railways (CFF), which are now being built to run over all the standard gauge lines

([1]) Office for Research and Experiments of the International Railway Union.

of Western Europe with the exception of the three-phase lines. These rakes require four pantographs fitted with four different bows. The use of these different pantographs is not due to the four different types of current but to the different administrations.

### B. Selection of the supply system.

The problem of the selection of the supply system only arises in the case of polycurrent units. In order to run with several systems, it is necessary to provide special equipment which connects up, checks and locks the different branch circuits of the supply circuits, the traction motors, the auxiliary motors and equipment, and the controls. The duties carried out by this equipment can be done automatically, semi-automatically, or manually. Table 7 shows the application of the various systems of selecting the current and the equipment they use.

The solution using manual control is only applicable in simple cases. It has in fact only been used in the case of the Ale sets of the Italian State Railways (FS), the motor unit of which is in principle equipped with apparatus for 3 000 V D.C. In an adjoining unit, there is a transformer-rectifier group which assures the supply of the motor unit with 3 000 V D.C. on sections electrified with 3 600 V three-phase 16 2/3 cycles. In this case, the selection gear merely consists of a simple locking device for the pantograph and main circuit breakers.

Although automatic systems have much to commend them, their field of use is very restricted. They can only be used if the units are equipped with a single type of pantograph which can be used with all the systems in question. This is the case in particular with shunting locomotives in the transition stations, such as that of the CFF at Basle. As such locomotives frequently have to change from the 15 kV 16 2/3-cycle system to the 25 kV 50-cycle system, and vice versa everything possible has been done to facilitate this. The neutral sections are run through without lowering the pantograph. To avoid arcing and short circuits when this is done, the main circuit breaker merely has to be released, and this moreover takes place automatically if forgotten.

If the change from one system to another involves lowering and possibly changing the pantograph, this can no longer be done automatically, as it has to be put into circuit with the contact line before it can be used. The driver has therefore to take action, so that the system of selection is a semi-automatic one. When a manually operated selector is provided, it can be used for other functions as well as the selection of the pantograph. The solutions to date are shown in Table 7. It should be pointed out, however, that an automatic device only makes it possible to check if the system of current corresponds to the particular pantograph raised, but not that the latter is the correct one from the point of view of the gauge.

The most universal solution is that chosen in the case of the TEE sets of the CFF, which are designed to run over the lines of a great many administrations, with four different types of current. In each driving compartment, there is a whole series of push-buttons, one for each administration, and the corresponding pantograph. When the administration, whose lines are to be run over, has been decided, the correct pantograph is raised when the respective push-button is pressed. After this has been done, a system of voltage and frequency relays checks the current brought to the roof circuit, correctly groups the traction motors and the auxiliary converter group, and releases the respective circuit breaker.

### C. Cutting off the current.

The cutting off of the current takes place on all the polycurrent units by the main switches. This is not the case on single-current vehicles, especially in the case of low powers. Circuit breakers are

TABLE 4. — TECHNICAL DATA CONCERNI

| | *Category* a<br>*D.C. - D.C.* | | | | | |
|---|---|---|---|---|---|---|
| *Administration*<br>*Designation of unit* | *S.N.C.B.*<br>« Benelux » | | *Oe.B.B.*<br>E 1051.01 | | *C.F.F.*<br>Ee 3/3[II] 16501/02 | |
| *Current supply system* | 1 500 V | 3 000 V | 15 kV<br>16 2/3 c/s | 20 kV<br>50 c/s | 15 kV<br>16 2/3 c/s | 25 kV<br>50 c/s |
| *Maximum speed* . . . (km/h) | 125 | | 110 | | 45 | |
| *Continuous rating :* | | | | | | |
| *tractive effort* . . . . ((kg) | 2 680 | | 7 200 | | 5 800 | |
| *power* . . . . . (HP) | 832 | | 2 500 | 2 720 | 600 | |
| *at speed of* . . . . (km/h) | 81.5 | | 92.0 | 100.0 | 28.0 | |
| *One-hour rating :* | | | | | | |
| *tractive effort* . . . . (kg) | 3 420 | | 9 000 | | 7 000 | |
| *power* . . . . . (HP) | 1 000 | | 2 800 | | 690 | |
| *at speed of* . . . . (km/h) | 75.5 | | 82.0 | | 26.5 | |
| *Maximum tractive effort* (kg) | 5 220 | | 15 000 | | 13 100 | |
| *Weight :* | | | | | | |
| *in service order empty* . (t) | 115 | | 82 | | 45 | |
| *with load* . . . . . (t) | 132 | | 82 | | 45 | |
| *adhesion weight empty* . (t) | 64 | | 82 | | 45 | |
| *with load* . . . . . (t) | 73 | | 82 | | 45 | |
| *brake weight at different ratings* . . . . . (t) | | | 95/75/40 | | 45 | |
| *Driving wheel diameter :* | | | | | | |
| *new* . . . . . (mm) | 950 | | 1 350 | | 1 040 | |
| *worn* . . . . . (mm) | 870 | | 1 280 | | 980 | |
| *Carrying wheel diam. new* (mm) | 950 | | — | | — | |
| *worn* . . . . . (mm) | 870 | | — | | — | |
| *Load per driven axle* . . (t) | 18.25 | | 20.5 | | 15.0 | |
| *Load per carrier axle* . . (t) | 14.75 | | — | | — | |
| *Bogie centre distance* . (mm) | 18 350 | | 7 500 | | — | |
| *Total wheel base* . . . (mm) | 21 350 | | 10 700 | | 4 050 | |
| *Bogie wheel base* . . . (mm) | 3 000 | | 3 200 | | — | |
| *Minimum inscribed radius in curves* . . . . . (m) | 125 | | 120 | | 50 | |
| *Power transmission* . . . . . | Nose-suspended | | ELIN, rubber components | | Rods | |
| *Tangential springs* . . . . . | yes | | yes | | yes | |
| *Reduction gear* . . . . . | single | | single | | single | |
| *Reduction gear ratio* . . . . | 1 : 2.94 | | 1 : 3.62 | | 1 : 8.00 | |

## TI-CURRENT MOTIVE POWER UNITS

*Category* b
*A.C. - A.C.*

| *C.F.F.* 3/3[II] 16503/04 | | *C.F.F.* Ee 3/3[II] 16505/06 | | *S.N.C.F.* BB 30001/02 | | *S.N.C.F.* BB 30003/04 | | *S.N.C.F.* C 30101/09 | |
|---|---|---|---|---|---|---|---|---|---|
| kV / 3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| 45 | | 45 | | 160 | | 160 | | 45 | |
| 6 600 | | 5 800 | | 12 500 | | 13 300 | | 5 800 | |
| 705 | | 610 | | 4 170 | 4 240 | 3 820 | 4 760 | 615 | |
| 28.0 | | 28.5 | | 89.7 | 91.5 | 77.5 | 97.0 | 28.5 | |
| 7 150 | | 7 000 | | 14 000 | | 14 650 | | 7 000 | |
| 735 | | 690 | | 4 460 | | 4 040 | 5 120 | 690 | |
| 27.0 | | 26.5 | | 85.7 | | 74.5 | 94.5 | 26.5 | |
| 12 900 | | 13 500 | | 24 100 | | 21 000 | | 13 500 | |
| 46 | | 47 | | 85 | | loc. 30003 : 82 - 30004 : 84 | | 52 | |
| 46 | | 47 | | 85 | | loc. 30003 : 82 - 30004 : 84 | | 52 | |
| 46 | | 47 | | 85 | | loc. 30003 : 82 - 30004 : 84 | | 52 | |
| 46 | | 47 | | 85 | | loc. 30003 : 82 - 30004 : 84 | | 52 | |
| 45 | | 45 | | 78/68 | | 78/68 | | | |
| 1 040 | | 1 040 | | 1 250 | | 1 250 | | 1 040 | |
| 980 | | 980 | | 1 180 | | 1 180 | | 980 | |
| — | | — | | — | | — | | — | |
| — | | — | | — | | — | | — | |
| 15.3 | | 15.7 | | 21.3 | | loc.30003: 20.4 - 30004: 21.2 | | 17.3 | |
| — | | — | | — | | — | | — | |
| — | | — | | 9 200 | | 9 200 | | — | |
| 4 050 | | 4 050 | | 12 400 | | 12 100 | | 4 050 | |
| — | | — | | 3 200 | | 2 900 | | — | |
| 50 Rods yes single 1 : 7.16 | | 50 Rods yes single 1 : 7.16 | | 120 Jacquemin yes single 1 : 2.28 | | 120 Jacquemin yes single 1 : 1.46 | | 120 Rods yes single 1 : 7.16 | |

TABLE 4. — TECHNICAL DATA CONCERN

| | Category : D | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Administration* | *F.S.* | | *S.N.C.F.* | | *S.N.C.F.* | | *S.N.C.F.* | | | | | |
| *Designation of unit* | Ale 840 | | CC 25001/09 | | BB 16500 | | BB 2004/05 | | | | | |
| *Current supply system* | 3 000 V | 3 600 VΔ 16 2/3 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 25 kV 50 c/s | 1500 V | 3000 V | 25 50 | | | |
| *Maximum speed* . . . (km/h) | 150 | | 100 | | 90/150 | | 100/140 | | | | | |
| *Continuous rating :* | | | | | | | | | | | | |
| *tractive effort* . . . . ((kg) | 2 560 | | | 16 000 | 10 250/ 7 000 | 19 200/ 11 300 | 16 900/11 000 | | | | | |
| *power* . . . . . (HP) | 700 | | | 4 040 | 930 | 3 440 | 2 810 | | | | | |
| *at speed of* . . . . .(km/h) | 76.0 | | | 68.0 | 24.5/42.0 | 48.0/82.0 | 46.0/69.0 | | | | | |
| *One-hour rating :* | | | | | | | | | | | | |
| *tractive effort* . . . . (kg) | 3 400 | | 9 800 | 17 400 | | 20 000/ 11 800 | 17 700/12 800 | | | | | |
| *power* . . . . . (HP) | 880 | | 400 | 4 200 | | 3 500 | 2 970 | | | | | |
| *at speed of* . . . . .(km/h) | 70.0 | | 11.0 | 65.0 | | 47.0/80.0 | 45.5/68.0 | | | | | |
| *Maximum tractive effort* (kg) | 6 600 | | 18 000 | 32 000 | 16 000/ 9 000 | 33 000/ 19 500 | 21 500/14 600 | | | | | |
| *Weight :* | | | | | | | | | | | | |
| *in service order empty* . (t) | 108 | | 106 | | 69 | | 69 | | | | | |
| *with load* . . . . . (t) | 120 | | 106 | | 69 | | 69 | | | | | |
| *adhesion weight empty* . (t) | 58 | | 106 | | 69 | | 69 | | | | | |
| *with load* . . . . . (t) | 64 | | 106 | | 69 | | 69 | | | | | |
| *brake weight at different ratings* . . . . . (t) | 123 | | 84/67 | | 51/44 | | 60/51 | | | | | |
| *Driving wheel diameter :* | | | | | | | | | | | | |
| *new* . . . . . (mm) | 1 040 | | 1 400 | | 1 100 | | 1 040 | | | | | |
| *worn* . . . . . (mm) | ? | | 1 320 | | 1 020 | | 980 | | | | | |
| *Carrying wheel diam. new*(mm) | 1 040 | | — | | — | | — | | | | | |
| *worn* . . . . . (mm) | ? | | — | | — | | — | | | | | |
| *Load per driven axle* . . (t) | 16.0 | | 17.7 | | 17.3 | | 17.3 | | | | | |
| *Load per carrier axle* . . (t) | 14.0 | | — | | — | | — | | | | | |
| *Bogie centre distance* . (mm) | 20 000 | | 9 000 | | 8 250 | | 8 200 | | | | | |
| *Total wheel base* . . . (mm) | 23 100 | | 13 200 | | 9 800 | | 10 400 | | | | | |
| *Bogie wheel base* . . . (mm) | 3 100 | | 4 200 | | 1 600 | | 2 200 | | | | | |
| *Minimum inscribed radius in curves* . . . . . (m) | 150 | | 120 | | 120 | | 120 | | | | | |
| *Power transmission* . . . . . | | | SLM | | Alsthom | | Jacquemin | | | | | |
| *Tangential springs* . . . . . | yes | | yes | | no | | no | | | | | |
| *Reduction gear* . . . . . | single | | single | | double | | double | | | | | |
| *Reduction gear ratio* . . . . | 1 : 2.18 | | 1 : 4.19 | | 1 : 3.22 / 1 : 1.88 | | 1 : 2.85 / 1 : 1.9 | | | | | |

**-CURRENT MOTIVE POWER UNITS** (*continued*)

| *C.F.F.* Ae 4/6III 10851 | | | *C.F.F.* TEE II | | | | *C.F.F.* Ee 3/3IV 16551/60 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| 110 | | | 160 | | | | 60 | | | |
| 6 600 | | | 8 140 | | 8 320 | 8 140 | 5 000 | | | |
| 2 000 | | | 2 700 | | 2 850 | 2 700 | 450 | | | |
| 87.0 | | | 90.0 | | 93.0 | 90.0 | 25.0 | | | |
| 7 800 | | | 9 560 | | 9 700 | 9 560 | 6 000 | | | |
| 2 300 | | | 3 000 | | 3 150 | 3 000 | 520 | | | |
| 83.0 | | | 85.0 | | 88.0 | 85.0 | 23.8 | | | |
| 13 600 | | | 16 000 | | 16 000 | 16 000 | 12 000 | | | |
| approx. 84 | | | motor coach : 96 | | | | 50 | | | |
| approx. 84 | | | motor coach : 96 | | | | 50 | | | |
| approx. 60 | | | 64 | | | | 50 | | | |
| approx. 60 | | | 64 | | | | 50 | | | |
| | | | | | | | 50 | | | |
| 1 230 | | | 1 100 | | | | 1 040 | | | |
| 1 170 | | | 1 040 | | | | 980 | | | |
| 950 | | | 940 | | | | — | | | |
| 890 | | | 880 | | | | — | | | |
| approx. 15.0 | | | 16.0 | | | | 16.7 | | | |
| approx. 12.0 | | | motor coach : 16.0 | | | | — | | | |
| — | | | motor coach : 17 100 | | | | — | | | |
| 12 800 | | | motor coach : 21 000 | | | | 4 000 | | | |
| — | | | motor coach : 3 900 | | | | — | | | |
| 114 | | | 125 | | | | 80 | | | |
| C with tangential springs | | | BBC with tangential springs | | | | Rods | | | |
| yes | | | yes | | | | yes | | | |
| single | | | single | | | | single | | | |
| 1 : 4.53 | | | 1 : 2.34 | | | | 1 : 6.75 | | | |

TABLE 5. — PANTOGRA

| | *Category* a *D.C.-D.C.* | | *Category* b *A.C.-A.C.* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Administration* *Designation of unit* | *S.N.C.B.* « Benelux » | | *Oe.B.B.* E 1051.01 | | *C.F.F.* Ee 3/3II 16501/06 | | *S.N.C.F.* BB 30001/04 | | *F.S.* Ale 840 | | *S.N.C.* CC 2500 | |
| *Current supply system* | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 20 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 3 000 V | 3 600 V Δ 16 2/3 c/s | 1 500 V | 2 50 |
| *Total number* . . . . . | 1 | 1 | 2 | | 1 | | 2 | | 2 | 2 × 2 | 2 | |
| *Number of types* . . . . | 1 | 1 | 1 | | 1 | | 1 | | 1 | 1 | 1 | |
| *Types* . . . . . | ? | ? | OeBB | | CFF-MFO | | AM 11 | | ? | 3 | MT | |
| *Position in relation to bogie centres or axles* . (mm) | ? | | approx. 340 | | 525 | | 180 | | 0 | | 200 | |
| *Has the pantograph been streamlined for both directions of running*? | no | | no | | no | | no | | no | | no | |
| *Control* . . . . . | in the pantograph | | on the roof | | in the pantograph | | by the side of the panto-graph | | in the pantograph | | in the pantogra | |
| *Type of control :* *Lifting by* . . . . . | springs | | springs | | springs | | springs | | springs | | spring | |
| *Lowering by* . . . . | air | | air | | air | | air | | air | | air | |

required to carry out the automatic selection of the supply system with the pantograph raised before the circuits are interlocked, or — in the case of semi-automatic selection — to prevent interlocking if the controls of the selected system do not correspond to the current received.

The technical characteristics of the circuit breakers used have been collected together in Table 8. It will be noticed that in the case of A.C., only pneumatic circuit breakers are used. It is a question of up-to-date equipment, which except in the case of the Ale sets of the FS, have a nominal power of 10 to 15 MVA and a maximum power of about 200 MVA. The Ale sets of the FS are fitted with less powerful circuit breakers in view of the lower power of the three-phase system supplied at 3 600 V. In the case of D.C., ultra-rapid circuit breakers are used. As pneumatic circuit breakers for A.C. are of a completely different design to the ultra-rapid circuit breakers for D.C., both types are normally provided on locomotives which have to run with both types of current. If there is one pantograph per type of current, it is not necessary to provide additional protective equipment; on the other hand, if the supply is obtained

ULTI-CURRENT VEHICLES

*Category* c
*D.C. - A.C.*

| *N.C.F.* 16500 | | *S.N.C.F.* BB 20004/05 | | | *C.F.F.* Ae 4/6III 10851 | | | *C.F.F.* TEE II | | | | *C.F.F.* Ee 3/3IV 16551/60 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V | 25 kV 50 c/s | 1 500 V | 3 000 V | 25 kV 50 c/s | 1 500 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| | 1 | 1 | | 1 | 2 | | | 4 | | | | 1 | | | |
| | 1 | 1 | | 1 | 2 | | | 4 | | | | 1 | | | |
| 4 | AM11 | | | | | 355/1 | | 355/1 | | | | | at Geneva 355/3 | | |
| | or | AM 18 | | AM17 | | | | 355/2 | | | | | at Chiasso 355/1 | | |
| 8 | AM17 | | | | | 355/3 | | 355/3 | | | | | | | |
| | | | | | | | | 355/4 | | | | | | | |
| | 100 | 0 | | | ? | | | 1 150 and 1 250 | | | | approx. 1 100 | | | |
| | no | no | | | no | | | no | | | | no | | | |
| | the side of the ntograph | by the side of the pantograph | | | by the side of the pantograph | | | by the side of the pantograph | | | | by the side of the pantograph | | | |
| | prings | springs | | | springs | | | springs | | | | springs | | | |
| | air | air | | | air | | | air | | | | air | | | |

through a collecting bar, it is necessary to provide a switch to separate the D.C. installation from the high tension A.C. installation.

## D. Supply of the traction motors and regulation of the speed.

1. *General.*

Supplying the traction motors and regulating the speed differs with D.C. and A.C. vehicles. Usually, the motors of D.C. vehicles are connected directly to the contact line, or during starting, through resistances. In the case of an A.C. vehicle, a transformer or transformer-rectifier group reduces the high tension supply to a voltage which can be regulated between 0 and about 500 to 1 000 V A.C. or D.C. (undulating), which is taken to the traction motors. It is the same in the case of polycurrent vehicles supplied with D.C. or A.C. alone. In the case of a few polycurrent vehicles running on both these types of current, both systems of supply and regulation are used, whilst on others one of the two systems of current is converted to the other, and the regulation takes place through a single device.

TABLE 6. — TECHNICAL D

| | *Category 1 Pantographs for D.C. only* | | | | | | |
|---|---|---|---|---|---|---|---|
| *Administration* | *S.N.C.B.* | | *F.S.* | *S.N.C.F.* | | *C.F.F.* | |
| *Designation of the type of pantograph* | ? | ? | ? | AM 14 | AM 18 | 355/2 | 355/3 |
| *Used on networks* | N.S. 1 500 V | S.N.C.B. 3 000 V | F.S. 3 000 V | S.N.C.F. 1 500 V | S.N.C.F./ S.N.C.B. 1 500/3 000 V | N.S./ S.N.C.B. 1 500/3 000 V | S.N.C.F 1 500 V |
| *Rated voltage* (kV) | 3 | 3 | 7.5 | 25 | 25 | 25 | 25 |
| *Static application pressure* (kg) | 9.5 | 7.5 | 8.0 | 9.0 | 9.0 | 8.0 | 9. |
| *Height of contact wire :* | | | | | | | |
| *minimum* (mm) | 4 800 | 4 800 | 4 500 | 4 600 | 4 600 | 4 800 | 4 600 |
| *normal* (mm) | 5 500 | 5 100 | 5 000 | 5 750 | 5 750 | 5 300 | 5 750 |
| *maximum* (mm) | 5 750 | 6 200 | 5 800 | 6 500 | 6 500 | N.S. 5 500 S.N.C.B. 6250 | 6 450 |
| *Maximum height of pantogr.:* | | | | | | | |
| *lowered* (mm) | 4 400 | 4 400 | 3 800 | 4 195 | 4 195 | 4 200 | 4 200 |
| *raised* (mm) | 5 880 | 6 565 | — | 6 655 | 6 655 | N.S. 5 880 S.N.C.B. 6700 | 6 700 |
| *Maximum permissible stagger of contact wire* (mm) | ± 390 | ± 300 | ± 200 | ± 300 | ± 300 | ± 400 | ± 400 |
| *Total width of bow* (mm) | 1 950 | 1 760 | 1 430 | 1 960 | 1 960 | 1 950 | 1 950 |
| *Total width of friction strips* (mm) | 1 300 | 1 100 | — | 1 240 | 1 240 | 1 020 | 1 020 |
| *Lateral edges* | metal | metal | metal | metal | metal | insulating | insulatin |
| *Number of friction strips per bow* | 3 | 2 | 1 | 4 | 4 | 4 | 4 |
| *Number of bows per pantograph* | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| *Material of friction strips* | metallised carbon | carbon | copper | steel/ copper | steel/ copper | metallised carbon | steel/ copper |
| *Lubrication* | — | yes | yes | — | — | — | yes |
| *Maximum current taken* (A) | 900 | 450 | 400 | 3 500 | 3 500 | 3 500 | 3 500(1) |

(1) Loc. Ee 3/3IV 16551/60 at Geneva 1 500 V D.C. and 15 kV, 16 2/3 c/s.

IE PANTOGRAPHS

| | *Category 2 Pantographs for A.C. only* | | | | | *Category 3 Pantographs for D.C. and A.C.* | |
|---|---|---|---|---|---|---|---|
| *.B.B.* | *C.F.F.* | | *S.N.C.F.* | | *F.S.* | *S.N.C.F.* | *C.F.F.* |
| | MFO | 355/4 | AM 11 | AM 17 | 3 | MT | 355/1 |
| B./D.B. | C.F.F. | D.B./Oe.B.B. | S.N.C.F. | S.N.C.F. | F.S. | S.N.C.F. | C.F.F./ S.N.C.F./F.S. |
| kV /3 c/s nd 50 c/s | 15 kV 16 2/3 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 25 kV 50 c/s | 3 600 VΔ 16 2/3 c/s | 25 kV 50 c/s (and 1 500 V) Savoy network | 15 kV 16 2/3 c/s 25 kV 50 c/s 3 000 V |
| 15 | 25 | 25 | 25 | 25 | 7.5 | 25 | 25 |
| 5.5 | 5.5 | 7.0 | 7.0 | 7.0 | 12.0 | 7.0 | 7.0 |
| 950 | 4 800 | 4 950 | 4 650 | 4 650 | 4 650 | 4 650 | 4 500 |
| 750 | 5 500 | 5 750 | 5 750 | 5 750 | 5 000 | 5 750 | 5 500 |
| 300 | 6 000 | 6 200 | 6 500 | 6 500 | 5 500 | 6 500 | 6 450 |
| 590 | 4 580 | 4 200 | 4 280 | 4 280 | 3 800 | 4 280 | 4 200 |
| — | 6 700 | 6 700 | 6 740 | 6 740 | — | 6 710 | 6 700 |
| 400 | ± 200 | ± 400 | ± 300 | ± 300 | ± 50 | ± 300 | ± 300 |
| 950 | 1 320 | 1 950 | 1 600 | 1 600 | 833 | 1 600 | 1 450 |
| 000 | 600 | 1 020 | 1 060 | 1 060 | 614 | 1 060 | 680 |
| etal | metal | insulating | insulating | insulating | metal | insulating | insulating |
| 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| rbon | aluminium | carbon | steel | steel | copper | carbon | copper |
| — | yes | — | — | — | — | — | yes |
| 300 | 400 | 400 | 200 | 200 | 290 | 200 (2) | 1 500 |

00 V D.C. used at reduced power only.

TABLE 7. — SYS

| | *Category* a *D.C.-D.C.* | | *Category* b *A.C.-A.C.* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Administration* *Designation of unit* | *S.N.C.B.* « Benelux » | | *Oe.B.B.* E 1051.01 | | *C.F.F.* Ee 3/3II 16501/06 | | *S.N.C.F.* BB 30001/04 | | *F.S.* Ale 840 | | *S.N.C.* CC 2500 | |
| *Current supply system* | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 20 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 3 000 V | 3 600 V∆ 16 2/3 c/s | 1 500 V | 25 50 |
| *The current supply system is selected* . . . . . | semi-automatically | | automatically | | automatically | | automatically | | manually | | automatic | |
| *Number of types of pantographs* . . . . . | 2 | | 1 | | 1 | | 1 | | 2 | | 1 | |
| *Selection dependent on pantograph* . . . . . | yes | | no | | no | | no | | yes | | no | |
| *Selection acts only if main circuit breaker is closed* . | no | | yes | | yes | | yes | | no | | no | |
| *Gear to be operated by the driver* . . . . . | switch | | — | | — | | — | | feeder circuits of the electrically operated pantograph valves | | — | |
| *The system selection works automatically* . . . . . | — | | after closing of main circuit breaker | | after closing of main circuit breaker | | after closing of main circuit breaker | | — | | after raisi of pantogra | |
| *The selection device acts automatically on the circuits of the* . . . . . | — | | traction motors (auxiliary poles shunted) | | auxiliaries (and — in the case of locomotives 16503/04 — the traction motor shunts) | | auxiliaries (and — in the case of locomotives 30001/02 — the traction motor shunts) | | — | | converte set and heating | |
| *Testing device to verify whether correct system has been selected* . . . . . | yes acts after raising of pantograph | | no | | no | | no | | — | | no | |
| *Apparatus locked by the selection of control device* | — | main circuit breaker if switch is in 1 500 V position | — | | — | | — | | A.C. circuit breaker | D.C. circuit breaker | A.C. circuit breaker | Sel tic swi |

ECTION

| | | *Category* c<br>*D.C.-A.C.* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *S.N.C.F.*<br>BB 16500 | | *S.N.C.F.*<br>BB 20004/05 | | | *C.F.F.*<br>Ae 4/6[III] 10851 | | | *C.F.F.*<br>Ee 3/3[IV] 16551/60 | | | | *C.F.F.*<br>TEE II | | | |
| 0 V | 25 kV<br>50 c/s | 1 500 V | 3 000 V | 25 kV<br>50 c/s | 1 500 V | 15 kV<br>16 2/3<br>c/s | 25 kV<br>50 c/s | 1 500 V | 3 000 V | 15 kV<br>16 2/3<br>c/s | 25 kV<br>50 c/s | 1 500 V | 3 000 V | 15 kV<br>16 2/3<br>c/s | 25 kV<br>50 c/s |
| emi-auto-<br>matically | | semi-automatically | | | semi-automatically | | | automatically | | | | semi-automatically | | | |
| 2 | | 2 | | | 2 | | | 1 | | | | 4 | | | |
| yes | | yes | | | no | | | no | | | | no | | | |
| no | | no | | | no | | | no | | | | no | | | |
| ndividual<br>switches<br>for<br>C. or A.C.<br>ntographs | | individual switches for D.C. pantographs (two positions, 1 500 V and 3 000 V) and A.C. pantograph | | | correct choice of pantograph | | | — | | | | Separate push-button for each network and supply system concerned. The appropriate pantograph is then automatically selected | | | |
| after<br>lection of<br>antograph | | after selection of pantograph and system | | | after raising the pantograph | | | after raising the pantograph | | | | after raising the pantograph | | | |
| traction<br>motors,<br>auxiliaries<br>and<br>heating | | traction motors, auxiliaries and heating | | | traction motors, auxiliaries and heating | | | traction motors and auxiliaries | | | | traction motors, auxiliaries and heating | | | |
| es | no | yes, acting after raising of pantograph | | | no | | | no | | | | no | | | |
| .C.<br>ir-<br>uit<br>ea-<br>er | — | ? | | | A.C. main circuit breaker | | D.C. main circuit breaker | A.C. main circuit breaker | | D.C. main circuit breaker | | A.C. main circuit breaker | | D.C. main circuit breaker section switch | |

TABLE 8. — TECHNICAL DA

| | *Category* a *D.C. - D.C.* | | *Category* b *A.C. - A.C.* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Administration* *Type designation of unit* | *S.N.C.B.* « Benelux » | | *Oe.B.B.* E 1051.01 | | *C.F.F.* Ee 3/3II 16501/06 | | *S.N.C.F.* BB 30001/04 | | *F.S.* Ale 840 | | *S.N.C.F.* CC 25001/0 | |
| *Current supply system* | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 20 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 3 000 V | 3 600 V Δ 16 2/3 c/s | 1 500 V | 25 k 50 c/ |
| *Number of circuit breakers* | 2 | | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 |
| *Number of types of circuit breakers* . . . . . | 1 | | 1 | | 1 | | 1 | | 1 | 1 | 1 | 1 |
| *Designat. of circuit breaker* | — | | DBTF 30 i 200 | | DBTF 30 i 250 | | DBTF 30 i 200 | | — | — | IRT 47 E | MFC |
| *Mounting* . . . . . | below vehicle frame | | in the roof | | on the roof | | on the roof | | — | — | com-partment | com-part-men |
| *Used for closing or opening the main circuit* . . . . . | yes | | yes | | yes | | yes | | yes | yes | yes | yes |
| *Characteristics :* | | | | | | | | | | | | |
| *rated power* . . . MVA | 0.6 | | 10 | | 10 | | 10 | | 1.5 | 1.7 | 5.4 | 13 |
| *rated voltage* . . V | 3 000 | | 25 000 | | 25 000 | | 25 000 | | 3 000 | 3 600 | 1 800 | 25 000 |
| *rated amperage* . . A | 200 | | 400 | | 400 | | 400 | | 500 | 550 | 3 000 | 600 |
| *maximum rupturing capacity* . . . MVA | — | | 200 | | 250 | | 200 | | 5 | 24.5 | — | 200 |
| *maximum rupture current* . . . . A | — | | 8 000 | | 10 000 | | 8 000 | | — | — | 17 000 | 8 000 |
| *Rupture time :* | | | | | | | | | | | | |
| *mechanical* . . . . msec | — | | 152 | | 152 | | 152 | | 40 | — | — | 105 |
| *electrical, at rated power* . . . . msec | — | | 14 | | 14 | | 14 | | 10 | 15 | 20 | 37 |
| *corresponding relay times* . . . . . msec | — | | — | | — | | 28 | | 10 | — | — | 59 |
| *Circuit breaker control* . . . | electro-pneumatic | | electro-pneumatic | | electro-pneumatic | | electro-pneumatic | | — | — | elec-tro-mech-anical | elec-tro-pneu-matic |
| *Manual control* . . . . . | no | | — | | no | | no | | — | — | yes | yes |
| *Locking device :* | | | | | | | | | | | | |
| *min. locking pressure* HPZ | 3.0 | | — | | 2.5 | | 4.5 | | — | — | — | 2.0 |
| *min. release pressure* HPZ | — | | — | | 5.0 | | — | | — | — | — | — |

RCUIT BREAKERS

*Category* c
*D.C. - A.C.*

| *N.C.F.* 16500 | | *S.N.C.F.* BB 20004/05 | | | *C.F.F.* Ae 4/6III 10851 | | | *C.F.F.* TEE II | | | | *C.F.F.* Ee 3/3IV 16551/60 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| V | 25 kV 50 c/s | 1 500 V | 3 000 V | 25 kV 50 c/s | 1 500 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| | 1 | 1 | | 1 | 1 | 1 | | 1 | | 1 | | 1 | | 1 | |
| | 1 | 1 | | 1 | 1 | 1 | | 1 | | 1 | | 1 | | 1 | |
| | DBTF 30 i 200 | IRT 47 E | | DBTF 30 i 200 | URH 15 | DBTF 30 i 250 | | URH 15 | | DBTF 30 i 250 | | URH 4 | | DBTF 30 i 250 | |
| | on the roof | compart-ment | | com-part-ment | com-part-ment | on the roof | | compart-ment | | on the roof | | compart-ment | | on the roof | |
| | yes | yes | | yes | yes | yes | | yes | | yes | | yes | | yes | |
| | 10 | 5.4 | | 10 | — | 10 | | — | | 10 | | — | | 10 | |
| | 25 000 | 1 800 | | 25 000 | 3 600 | 25 000 | | 3 600 | | 25 000 | | 3 600 | | 25 000 | |
| | 400 | 3 000 | | 400 | 1 860 | 400 | | 1 860 | | 400 | | 600 | | 400 | |
| | 200 | — | | 200 | — | 250 | | — | | 250 | | — | | 250 | |
| | 8 000 | 17 000 | | 8 000 | 15 000 | 10 000 | | 15 000 | | 10 000 | | 4 000 | | 10 000 | |
| | 152 | — | | 152 | 1. . .5 | 152 | | 1. . .5 | | 152 | | 1. . .5 | | 152 | |
| | 14 | 20 | | 14 | appr. 40 | 14 | | approx. 40 | | 14 | | approx. 40 | | 14 | |
| | 28 | — | | 28 | — | — | | — | | — | | — | | — | |
| | elec-tro-pneu-matic | electro-mechanical | | elec-tro-pneu-matic | elec-tro-ma-gnetic | electro-pneumatic | | electro-magnetic | | electro-pneumatic | | electro-magnetic | | electro-pneumatic | |
| | no | yes | | no | no | yes | | no | | yes | | no | | yes | |
| | 4.5 | — | | 4.5 | — | 2.5 | | — | | 2.5 | | — | | 2.5 | |
| | — | — | | — | — | 5.0 | | — | | 5.0 | | — | | 5.0 | |

The various systems of supply to the traction motors and of speed regulation on the polycurrent units are listed in Table 9.

2. *D.C. units.*

As in practice the voltage of one system of supply is everywhere double that of the other system, the change of system presents no special difficulties. The dielectric rigidity of all cabling and equipment must be designed for the higher nominal voltage and the final grouping of the traction motors in parallel or series-parallel of the lower voltage cannot be used with the higher voltage. As a result, there is one less coupling in the case of the higher voltage. This drawback can be reduced by giving up coupling all the motors in series in the case of the lower voltage.

Mention may be made of a special solution used on the Rhaetian Railway (Switzerland); in 1957, this Railway put into service two 900 HP BoBo rail motor coaches intended to run during the winter on the 2 400 V line from Coire to Arosa, and during the summer on the 1 500 V line from Bellinzone to Mesocco. The traction motors of these vehicles (not listed in the tables) are supplied on the former line in series and series-parallel, and on the latter in series-parallel and parallel. The Administration accepts the resultant lower power on the Arosa line. As the above two lines are separate, the change-over from one system to the other is carried out in the shops.

3. *A.C. units.*

Supplying these polycurrent units does not present any special problems of any importance. The different values of the supply voltages can easily be compensated. As regards the traction motor circuits, compensation is preferably by means of the graduator, switches, etc., i.e. by the usual tension regulating device. If necessary the travel of this device can be limited whilst the unit is supplied at the higher voltage. In the case of units fitted with single-phase traction motors with series excitation, the higher voltages at the secondary of the transformer, supplied at 20 or 25 kV, 50 cycles, are compensated at least partially, as the voltage drops are greater than in the case of a supply at a frequency of 16 2/3 cycles.

4. *D.C. and A.C. units.*

The great difference between D.C. and A.C. in general necessitates the adoption of two supply systems simultaneously; one being the same as that of a D.C. unit and the other the same as that of an A.C. unit. It is therefore necessary to install for the regulation of the speed starting resistance with switches and a transformer with graduator. All units of this type, whether in service or under construction, are in addition fitted with rectifiers to supply the traction motors with D.C. or undulated current only. This solution is necessary for constructional reasons of the traction motors.

There have been a few special cases. One of these is the CC 25000 locomotive of the SNCF. These locomotives were designed in the first place for 25 kV 50 cycles A.C. To enable them to run with reduced power on 1 500 V D.C. they are fitted with a converter group. This group supplies the secondary winding of the main transformer when running on D.C. and the regulation of the speed takes place through the A.C. equipment. Another solution is that adopted by the FS for the twin Ale units running on 3 000 V D.C. and 3 600 V three-phase. The motor unit is fitted with all the 3 000 V D.C. equipment. For the three-phase supply, the trailer carries a transformer-rectifier group which supplies 3 000 V D.C. for the motor unit and the regulation of the speed is carried out by the D.C. equipment. A similar arrangement has been used on the BB 20004/5 locomotives of the SNCF. Another solution is that used for the four current shunting locomotives of the CFF. As space is very limited, no graduator or

switches will be fitted for the A.C. supplies and regulation will be by polarised grid rectifiers.

5. *Supply equipment.*

The design of a motor unit transformer is influenced by its power, the voltage and the frequency of the supply current, the choice of the regulation and supply system, and possibly by the space available. In the case of polycurrent units supplied by a single system of A.C. the same problems arise as in the case of designing a transformer for a single current machine. When the machine has to be supplied with two systems of A.C., the transformer must be adapted to the different voltages and frequencies. Consequently, the size and weight of the transformer depend upon the lower voltage and its insulation upon the higher voltage. In addition, it is necessary to fit a few additional tappings in order to provide the voltage required for the auxiliary and heating circuits.

The technical characteristics of the two-frequency transformers are collected together in Table 10.

As the proper functioning of a rectifier does not depend on the frequency of the supply current, all the rectifiers used for single current machines are suitable for polycurrent units. Only the smoothing-out self induction coils, and possibly the starting up, excitation, checking equipment, etc., need to be provided for both frequencies. The information listed in Table 11 shows that all sorts of rectifiers are used, with the exception of selenium rectifiers which would be much too bulky for the powers in question. On the other hand, silicon rectifiers have been used on a certain number of units, although such rectifiers have only recently been perfected for traction purposes. Silicon rectifiers have the advantage of being very small compared with the current and voltage with which they are used, whilst their efficiency is very good.

The speed regulating equipment, graduators, switches, etc., are of standard pattern in all cases. Only the higher voltage has to be taken into account, and in some cases, the need to block certain running notches with one or other supply system. It is the same as regards the other equipment, commutators, reverse gear, etc.

## E. Design of the traction motors.

The technical characteristics of the traction motors of polycurrent vehicles are shown in Table 12, which shows that the design of these motors depends a great deal upon the supply system to be used.

1. *D.C. units.*

The use of two different supply voltages does not give rise to any special difficulties in designing the traction motors. It will suffice to point out that all the motors must be insulated for the higher voltage, although the nominal voltage is lower, viz., the value of the lower supply voltage. From the point of view of the design and weight of a motor, a nominal voltage of 750 V would be more favourable, but this would make it necessary to provide eight motors in order to be able to have two groups of motors under the two supply voltages.

2. *A.C. units.*

For such units, two different types of motors are available. One is the A.C. series motor, supplied direct from the transformer, and the other the undulatory current motor supplied through a rectifier.

A.C. series motors must be designed for the higher frequency, i.e. for 50 cycles. The nominal voltage of these motors has to be relatively low. The consequence is that there is a great intensity of current and a large number of poles and carbon brushes. For high powers, tandem motors with two rotors and two collectors are used (E 1051.01 locomotive of the OeBB) or motors with multi-parallel windings (CC 25001/9 and BB 30001/2 locomotives of the SNCF and Ee $3/3^{II}$ 16503/4 of the CFF).

TABLE 9. — TRACTION MOTOR FI

| | *Category* a *D.C.-D.C.* | | | | | |
|---|---|---|---|---|---|---|
| *Administration* | *S.N.C.B.* | | *Oe.B.B.* | | *C.F.F.* | |
| *Type designation of unit* | « Benelux » | | E 1051.01 | | Ee 3/3II 16501/02 | |
| *Current supply system* | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 20 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| *Traction motor feed* . . . | direct (rheostat) | | transformer | | transformer/ rectifiers | |
| **A.C. :** | | | | | | |
| *Control by* . . . . . | — | | contactors | | low-tension graduator | |
| *Transition by* . . . . . | — | | chokes | | resistances and chokes | |
| *Type of drive* . . . . . | — | | electro-pneumatic | | electro-pneumatic motor | |
| *Emergency control* . . . | — | | — | | — | |
| *Total number of notches* . | — | | 21 | 21 | 24 | 18 |
| *Notches with series resistances* . . . . . | — | | — | — | — | — |
| *Notches that can be permanently connected* | — | | 19 | 19 | 24 | 18 |
| *Shunt field notches* . . | — | | — | — | — | — |
| *Notches for control by polarized grid rectifiers* . . . . . | — | | — | — | — | — |
| *Contactor locking* . . . . | — | | electric | | — | |
| **D.C. :** | | | | | | |
| *Number of notches (excl. shunt field notches) :* | | | | | | |
| *in series connection* . . | — | 8 | | | | |
| *in series-parallel connect.* | 8 | 7 | | | | |
| *in parallel connection* . | 7 | — | | | | |
| *Type of control device* . . | Cam shaft contactors | | | | | |
| *Duration load capacity of starting resistances in per-cent of full load* . . | ? | | | | | |
| *Change of traction motor connection* . . . . . | bridge | bridge | | | | |
| *Shunt field notches :* | | | | | | |
| *in series connection* . . | — | 2 | | | | |
| *in series-parallel connect.* | 2 | 3 | | | | |
| *in parallel connection* . | 3 | — | | | | |
| *Maximum field weakening (ratio of field current and armature current) :* | | | | | | |
| *in series connection* . . | — | 45 | | | | |
| *in series-parallel connect.* | 45 | 45 | | | | |
| *in parallel connection* . | 45 | — | | | | |
| *Type of shunts* . . . . . | ohmic/inductive | | | | | |

EMS AND SPEED CONTROL

*Category* b
*A.C.-A.C.*

| *C.F.F.* Ee 3/3II 16503/04 | | *C.F.F.* Ee 3/3II 16505/06 | | *S.N.C.F.* BB 30001/02 | | *S.N.C.F.* BB 30003/04 | |
|---|---|---|---|---|---|---|---|
| 5 kV 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| transformer | | transformer/ rectifiers | | transformer | | transformer/ rectifiers | |
| contactors chokes electro-pneumatic | | contactors chokes electro-pneumatic | | high-tension graduator resistance electro-pneumatic motor | | high-tension graduator resistance electro-pneumatic motor | |
| — | | — | | manual | | manual | |
| 20 | 20 | 18 | 16 | 30 | 30 | 32 | 32 |
| — | — | — | — | — | — | — | — |
| 20 | 20 | 18 | 16 | 30 | 30 | 32 | 32 |
| — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — |
| electric | | electric | | — | | — | |

| | Categor | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Administration* | *F.S.* | | *S.N.C.F.* | | *S.N.C.F.* | | *S.N.C.F.* | | |
| *Type designation of unit* | Ale 840 | | CC 25001/09 | | BB 16500 | | BB 20004/05 | | |
| *Current supply system* | 3 000 V | 3 600 V Δ 16 2/3 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 3 000 V | 25 kV 50 c/ |
| *Traction motor feed* | direct (rheostat) | transformer/ rectifiers (rheostat) | converter/ transformer (secondary winding) | transformer | direct (rheostat) | transformer/ rectifiers | direct (rheostat) | | transf formers rectifi (rheost |
| **A.C. :** | | | | | | | | | |
| *Control by* | — | | contactors | | — | high-tension graduator | — | | |
| *Transition by* | — | | chokes | | — | resistance | — | | |
| *Type of drive* | — | | electro-pneumatic | | — | electric motor | — | | |
| *Emergency control* | — | | — | | — | manual | — | | |
| *Total number of notches* | — | | 16 | | — | 38 | — | | |
| *Notches with series resistances* | — | | — | | — | 19 | — | | |
| *Notches that can be permanently connected* | — | | 16 | | — | 19 | — | | |
| *Shunt field notches* | — | | — | | — | — | — | | |
| *Notches for control by polarized grid rectifiers* | — | | — | | — | — | — | | |
| *Contactor locking* | — | | electric | | — | — | — | | |
| **D.C. :** | | | | | | | | | |
| *Number of notches (excl. shunt field notches) :* | | | | | | | | | |
| *in series connection* | 11 | | — | | 6 | — | — | 28 | — |
| *in series-parallel connect.* | 8 | | — | | — | — | — | — | — |
| *in parallel connection* | — | | — | | — | — | 28 | — | 28 |
| *Type of control device* | electro-pneumatic contactors | | — | | Contactors | — | Resistance graduator driven by electro-pneumatic motor | | |
| *Duration load capacity of starting resistances in per-cent of full load* | ? | | — | | 100 | — | 100 | 100 | 100 |
| *Change of traction motor connection* | shunt | | — | | — | — | — | — | — |
| *Shunt field notches :* | | | | | | | | | |
| *in series connection* | 5 | | — | | — | — | — | 6 | — |
| *in series-parallel connect.* | 4 | | — | | — | — | — | — | — |
| *in parallel connection* | — | | — | | — | — | 6 | — | 6 |
| *Maximum field weakening (ratio of field current and armature current) :* | | | | | | | | | |
| *in series connection* | 35 | | — | | — | — | — | 30 | — |
| *in series-parallel connect.* | 46 | | — | | — | — | — | — | — |
| *in parallel connection* | — | | — | | — | — | 30 | — | 30 |
| *Type of shunts* | several windings | | — | | — | — | ohmic/inductive | | |

| | *C.F.F.* Ae 4/6III 10851 | | *C.F.F.* TEE II | | | | *C.F.F.* Ee 3/3IV 16551/60 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| ct tat) | | transformer/ rectifiers | | direct (rheostat) | | transformer/ rectifiers | | direct (rheostat) | | transformer/ rectifiers | |
| | | high-tension graduator | | — | | contactors | | — | | rectifier grids | |
| | | resistance | | — | | choke and resistance | | | | | |
| | | electro-pneumatic | | — | | electro-pneumatic | | | | | |
| | | motor | | | | | | | | | |
| | | manual | | — | | — | | — | | | |
| | | 32 | 22 | — | | 27 | 23 | — | | 24 | 24 |
| | | — | — | — | | 12 | 12 | — | | — | — |
| | | 32 | 22 | — | | 27 | 23 | — | | 24 | 24 |
| | | — | — | — | | — | — | — | | 5 | 5 |
| | | — | — | — | | — | — | — | | 19 | 19 |
| | | — | | — | | electric | | — | | — | |
| | | — | | — | 13 | — | | — | 15 | — | |
| | | — | | 13 | 13 | — | | — | — | — | |
| | | — | | 13 | — | — | | 15 | — | — | |
| n- ft ac- s | | — | | electro-pneumatic contactors | | — | | electro-pneumatic contactors | | — | |
| | | — | | 100 | 100 | — | | 100 | 100 | — | |
| ge | | — | | bridge | bridge | — | | — | — | — | |
| | | — | | — | 4 | — | | — | 5 | — | |
| | | — | | 4 | 4 | — | | — | — | — | |
| | | — | | 4 | — | — | | 5 | — | — | |
| | | — | | — | 33 | — | | — | (appr. 60) | — | |
| | | — | | 33 | 50 | — | | — | — | — | |
| | | — | | 50 | — | — | | (appr. 60) | — | (approx. 60) | |
| | | — | | ohmic/inductive | | — | | Variation of separate excitation | | | |

TABLE 10. — TRANSFORM

| | Categc | | | |
|---|---|---|---|---|
| *Administration* / *Designation of unit* | *Oe.B.B.* E 1051.01 | | *C.F.F.* Ee 3/3II 16501/02 | |
| *Current supply system* | 15 kV 16 2/3 c/s | 20 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| *Number of transformers* | 1 | | 1 | |
| *Rated power for the secondary windings :* | | | | |
| *Traction* (kVA) | 1 950 | 2 600 | 800 | 900 |
| *Heating* (kVA) | | | — | — |
| *Auxiliaries* (kVA) | | | 37 | 40 |
| *Rated voltage of the secondary windings :* | | | | |
| *Traction* (V) | 376 | 460 | 1 765 | 1 985 |
| *Heating* (V) | 1 000/800 | 1 060 | — | — |
| *Auxiliaries* (V) | 98 | 131 | 236 | 262 |
| *Maximum current of the secondary windings :* | | | | |
| *Traction* (A) | 8 700 | 8 700 | 1 450 | 1 450 |
| *Heating* (A) | 400 | 400 | — | — |
| *Auxiliaries* (A) | | | | |
| *Commutation for different catenary voltages* | no | | for the auxiliaries | |
| *Cooling* | separate | | self-ventilated | |
| *Circulating pump* | yes | | no | |
| *Oil radiators* | yes | | yes | |
| *Voltage regulation* | low-tension | | medium-tension | |
| *Weight with oil* (kg) | 8 820 | | — | |
| *Weight without oil* (kg) | 7 170 | | — | |
| *Special measures to reduce weight* | — | | radial plates | |
| *Special winding for auxiliary equipment* | no | | yes | |
| *Control device* | contactors | | graduator | |

ARACTERISTICS

| | *C.F.F.* Ee 3/3[II] 16503/04 | | *C.F.F.* Ee 3/3[II] 16505/06 | | *S.N.C.F.* BB 30001/02 | | *S.N.C.F.* BB 30003/04 | |
|---|---|---|---|---|---|---|---|---|
| | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| | 1 | | 1 | | 1 | | 1 | |
| | 500<br>—<br>35 | 835<br>—<br>35 | 480<br>—<br>40 | —<br>40 | 2 840<br>423/273<br>87 | 4 730<br>752/455<br>146 | 3 270<br>430/270<br>150 | 4 900<br>650/405<br>230 |
| | 270<br>—<br>248 | 450<br>—<br>250 | 1 214<br>—<br>258 | —<br>—<br>258 | 258<br>940/606<br>146/397 | 430<br>1 570/1 010<br>418/244/662 | 1 735<br>937/603<br>2 × 212<br>2 × 142<br>2 × 124 | 2 600<br>1 436/904<br>2 × 319<br>2 × 212<br>2 × 186 |
| | 4 400<br>— | 4 400<br>— | 1 200<br>— | 1 200<br>— | 22 000<br>560<br>220 | 22 000<br>560<br>220 | 4 000<br>560<br>360 | 4 000<br>560<br>360 |
| | for the auxiliaries | | for the auxiliaries | | for the auxiliaries | | for the auxiliaries | |
| | self-ventilated | | self-ventilated | | separate | | separate | |
| | no | | no | | yes | | yes | |
| | yes | | yes | | yes | | yes | |
| | low-tension | | medium-tension | | high-tension | | high-tension | |
| | 4 900 | | 8 200 | | 13 100 | | 12 350 | |
| | 3 700 | | 6 430 | | — | | — | |
| | — | | — | | — | | radial plates | |
| | yes | | yes | | yes | | yes | |
| | contactors | | contactors | | graduator | | graduator | |

TABLE 10. — TRANSFORM

| | | | | | | Categ D |
|---|---|---|---|---|---|---|
| *Administration* | *F.S.* | | *S.N.C.F.* | | *S.N.C.F.* | |
| *Designation of unit* | Ale 840 | | CC 25001/09 | | BB 16500 | |
| *Current supply system* | 3 000 V | 3 600 VΔ 16 2/3 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 25 k 50 c/ |
| *Number of transformers* | — | 1 | — | 1 | — | 1 |
| *Rated power for the secondary windings :* | | | | | | |
| *Traction* (kVA) | — | 3 × 245 | — | 2 450 | — | 2 85 |
| *Heating* (kVA) | — | — | — | 540 | — | 67 |
| *Auxiliaries* (kVA) | — | — | — | 70 | — | 14 |
| *Rated voltage for the secondary windings :* | | | | | | |
| *Traction* (V) | — | 1 430 | — | 575 | — | 1 58 |
| *Heating* (V) | — | — | — | 1 380 | — | 1 554/1 |
| *Auxiliaries* (V) | — | — | — | 402 | — | 1 55 |
| *Maximum current of the secondary windings :* | | | | | | |
| *Traction* (A) | — | 3 × 425 | — | 13 500 | — | 1 90 |
| *Heating* (A) | — | — | — | 560 | — | 55 |
| *Auxiliaries* (A) | — | — | — | 184 | — | — |
| *Commutation for different catenary voltages* | — | — | — | — | — | — |
| *Cooling* | — | separate | — | separate | — | separa |
| *Circulating pump* | — | no | — | yes | — | yes |
| *Oil radiators* | — | no | — | yes | — | yes |
| *Voltage regulation* | — | — | — | low-tension | — | high-ten |
| *Weight with oil* (kg) | — | 3 150 | — | 6 620 | — | 7 70 |
| *Weight without oil* (kg) | — | 3 150 | — | 5 420 | — | 6 07 |
| *Special measures to reduce weight* | — | — | — | — | — | — |
| *Special winding for auxiliary equipment* | — | separate transformers | — | no | — | yes |
| *Control device* | — | series resitances | — | contactors | — | graduat |

**ARACTERISTICS** (*continued*)

| | *S.N.C.F.* BB 20004/05 | | | *C.F.F.* Ae 4/6III 19851 | | | *C.F.F.* TEE II | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 500 V | 3 000 V | 25 kV 50 c/s | 1 500 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| | — | — | 1 | — | 1 | | — | — | 1 | |
| | — | — | approx. 3 000 | — | 1 850 | 1 850 | — | — | 2 140 | 2 230 |
| | — | — | — | — | 319 | 319 | — | — | 123 | 123 |
| | — | — | — | — | 25 | 25 | — | — | 333 | 333 |
| | — | — | 2 × 1 950 | — | 1 670 | 1 670 | — | — | 2 020 | 2 020 |
| | — | — | 1 500 | — | 1 008 | 1 680 | — | — | 1 540 | 1 540 |
| | — | — | 380/220 | — | 202/121 | 336/202 | — | — | 1 850 | 1 850 |
| | — | — | 950 | — | 1 900 | 1 900 | — | — | 2 400 | 2 400 |
| | — | — | 550 | — | | | — | — | 80 | 80 |
| | — | — | — | — | | | — | — | 200 | 200 |
| | — | — | — | — | for the auxiliaries | | — | — | for the auxiliaries | |
| | — | — | separate | — | separate | | — | — | separate | |
| | — | — | yes | — | yes | | — | — | yes | |
| | — | — | yes | — | yes | | — | — | yes | |
| | — | — | — | — | high-tension | | — | — | low-tension | |
| | — | — | 5 650 | — | | | — | — | 11 800 | |
| | — | — | | — | | | — | — | 9 900 | |
| | — | — | radial plates | — | radial plates | | — | — | orientated and lacquered plates | |
| | — | — | yes | — | yes | | — | — | yes | |
| | — | — | series resistances | — | graduator | | — | — | contactors | |

TABLE 11. — RECTIF

| | Category b A.C. - A.C. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Administration<br>Designation of unit | C.F.F.<br>Ee 3/3II 16501/02 | | C.F.F.<br>Ee 3/3II 16505/06 | | S.N.C.F.<br>BB 30003 | | S.N.C.F.<br>BB 30004 | |
| Current supply system | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 k 50 c/ |
| *Type of rectifier* | Excitron | | Excitron | | Semi-conductor | | Excitron | |
| *Makers* | BBC | | SAAS | | SW | | BBC | |
| *Type designation* | L 71a | | A 24 | | — | | Lgg 91a | |
| *Characteristic data :* | | | | | | | | |
| *Rated power* (kW) | 546 | | 2 × 340 | | 3 860 | | 1 135 | |
| *Rated voltage* (V) | 650 | | 850 | | 1 700 | | 1 000 | |
| *Rated current* (A) | 890 | | 2 × 400 | | 2 270 | | 1 135 | |
| *Maximum voltage* (V) | 900 | | 1 500 | | — | | — | |
| *Maximum current* (A) | 1 400 | | 2 × 800 | | 4 000 | | 2 000 | |
| *Voltage at continuous rating* (V) | 650 | | 850 | | 1 700 | | 850 | |
| *Current at continuous rating* (A) | 780 | | 2 × 400 | | 2 270 | | 1 135 | |
| *Admissible duration of overload* | 1 450<br>during 1′<br>1 250<br>during 5′<br>1 100<br>during 15′ | | 2 × 800<br>during 10″<br>2 × 600<br>during 2′<br>2 × 500<br>during 15′ | | 4 000<br>during 30″<br>3 200<br>during 2′<br>— | | 1 600<br>during 2′<br>1 300<br>during 4′<br>— | |
| *Permissible load variation as a function of the voltage :* | | | | | | | | |
| *Voltage drop at nominal rating* (V) | 25 | | 25 | | — | | 18 | |
| *Efficiency at nominal load* (%) | — | | — | | — | | 98 | |
| *Rectifier connection* | Push-pull | | Push-pull | | Graetz | | Graetz | |
| *Number of elements :* | | | | | | | | |
| *in parallel* | 1 | | 1 | | 12 | | 2 | |
| *in series* | 1 | | 1 | | 16 | | 1 | |
| *Number of anodes per tank* | 1 | | 2 | | — | | 1 | |
| *Anode heating* | yes | | no | | — | | yes | |
| *Vacuum pump* | no | | no | | — | | no | |
| *Rectifier gas* | rare gas | | rare gas | | — | | rare gas | |
| *Grids* | 2 | | 4 | | — | | 2 | |

RACTERISTICS

*Category* c
*D.C.-A.C.*

| *F.S.* Ale 840 | | *F.S.* Ale 840 | | *S.N.C.F.* BB 16500 | | *S.N.C.F.* BB 20004/05 | | | *C.F.F.* Ae 4/6[III] 10851 | | | *C.F.F.* TEE II | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 00 | 3 600 V Δ 16 2/3 c/s | 3 000 V | 3 600 V Δ 16 2/3 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 3 000 V | 25 kV 16 2/3 c/s | 1 500 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| Excitron CGE | | Excitron TIBB | | Ignitron SW | | Ignitron SW | | | Semi-conductor SSW | | | Semi-conductor SSW | | | |
| — | | — | | 12 inch | | 12 inch | | | silicon | | | silicon Si 150 F | | | |
| 110 | | 110 | | 1 500 | | 1 500 | | | 1 250 | | | — | | | |
| 1 500 | | 1 500 | | 1 200 | | 1 200 | | | 1 000 | | | — | | | |
| 75 | | 75 | | 1 250 | | 1 250 | | | 1 250 | | | — | | | |
| 3 150 | | 3 150 | | 1 200 | | 1 500 | | | 1 000 | | | 2 500 | | | |
| 200 | | 200 | | 1 900 | | 950 | | | 2 500 | | | 1 280 | | | |
| 1 300 | | 1 300 | | 1 100 | | 1 500 | | | — | | | — | | | |
| 67 | | 67 | | 1 250 | | 760 | | | — | | | — | | | |
| 85 during 1 h | | 85 during 1 h | | 1 900 during 2′ | | 950 during 1′ | | | — | | | — | | | |
| 90 dur. ½ h | | 90 dur. ½ h | | 1 400 during 10′ | | 850 during 10′ | | | — | | | — | | | |
| 260 during 5″ | | 260 during 5″ | | — | | — | | | — | | | — | | | |
| 15.5 | | 15.5 | | 20 to 800A | | 20 to 800A | | | — | | | — | | | |
| 99 | | 99 | | 98.3 | | 98.5 | | | — | | | 99.6 | | | |
| Graetz 6 elements | | Graetz 6 elements | | Push-pull | | Push-pull | | | Graetz | | | Graetz | | | |
| 1 | | 1 | | 1 | | 1 | | | — | | | 4 | | | |
| 1 | | 1 | | 1 | | 1 | | | — | | | 7 | | | |
| 1 | | 1 | | 1 | | 1 | | | — | | | — | | | |
| yes | | yes | | yes | | yes | | | — | | | — | | | |
| no | | no | | no | | no | | | — | | | — | | | |
| Hg | | Xenon | | — | | — | | | — | | | — | | | |
| 2 | | 2 | | 2 | | 2 | | | — | | | — | | | |

TABLE 11. — RECTIF

| | *Category* b *A.C. - A.C.* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Administration* *Designation of unit* | *C.F.F.* Ee 3/3II 16501/02 | | *C.F.F.* Ee 3/3II 16505/06 | | *S.N.C.F.* BB 30003 | | *S.N.C.F.* BB 30004 | |
| *Current supply system* | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| *Preliminary heating* | no | | no | | — | | yes | |
| *Minimum temperature at which the rectifier is able to work* °C | — | | — | | — | | — | |
| *Ignition by* | projection | | rod | | — | | projection | |
| *Minimum ignition voltage* | — | | — | | — | | 8 kV at the catena | |
| *Cooling system* | air | | air | | air 2 m³/sec | | air 45 m³/sec for 4 tubes | |
| *Auxiliary power absorbed at continuous rating* (VA) | — | | — | | — | | approx. 23 000 | |
| *Control* | temperature ignition cooling back-fire | | temperature ignition | | testing of elements excess current | | temperature asymmetry overload | |
| *Control acting on* | pilot lights circuit breaker | | pilot lights | | circuit breaker | | pilot lights circuit breaker | |
| *Rectifier mounting* | elastic | | elastic | | — | | elastic | |
| *Maximum acceleration* | 3 g | | 5 g | | — | | — | |
| *Specific weight :* | | | | | | | | |
| *with coolant* kg/kW | — | | — | | 0.39 | | 1.39 | |
| *without coolant* kg/kW | — | | — | | | | — | |
| *Smoothing choke* | yes | | yes | | yes | | yes | |
| *Ripple of rectified one-hour current* $\frac{Imax - Imin}{Imax + Imin} \cdot 100$ | 30 | | 28 | | 50 | | 50 | |
| *Notes* | — | | (1) | | — | | — | |

(1) The same rectifiers are envisaged for the S.N.C.F. locomotives C 30101/09 and the C.F.F. locomotives Ee 3

**RACTERISTICS** (*continued*)

*Category* c
*D.C.-A.C.*

| *F.S.* Ale 840 | | *F.S.* Ale 840 | | *S.N.C.F.* BB 16500 | | *S.N.C.F.* BB 20004/05 | | | *C.F.F.* Ae 4/6III 10851 | | | *C.F.F.* TEE II | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 3 600 V Δ 16 2/3 c/s | 3 000 V | 3 600 V Δ 16 2/3 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 3 000 V | 25 kV 50 c/s | 1 500 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| | yes | | no | | yes | | | yes | | — | | | | — | |
| | — | | — | | + 20 | | | + 20 | | — | | | | — | |
| | — | | projection | | igniter | | | igniter | | — | | | | — | |
| | 59 V | | 59 V | | — | | | — | | — | | | | — | |
| | air | | air | | water 7 lt/sec under 12.5 m | | | water 7 lt/sec under 12.5 m | | air 0.8 m³/sec | | | | air 0.8 m³/sec | |
| | 800 | | 800 | | appr. 600 | | | appr. 600 | | — | | | | — | |
| | temper-ature | | temper-ature | | temper-ature back-fire | | | temper-ature back-fire | | — | | | | — puncture overload | |
| | pilot light short-circuit | | pilot light short-circuit | | pilot light circuit breaker | | | pilot light circuit breaker | | — | | | | circuit breaker | |
| | elastic | | elastic | | elastic | | | elastic | | — | | | | — | |
| | 1.2 | | 1.4 | | 0.67 | | | 0.79 | | — | | | | — | |
| | — | | — | | 0.58 | | | 0.69 | | — | | | | — | |
| | no | | no | | yes | | | yes | | yes | | | | no | |
| | approx. 0 | | approx. 0 | | 20 | | | 15 | | — | | | | 40 | |

1/60.

TABLE 12. — TRACTI

| | *Category* a *D.C. - D.C.* | | | | | |
|---|---|---|---|---|---|---|
| *Administration* *Type designation of unit* | *S.N.C.B.* « Benelux » | | *Oe.B.B.* E 1051.01 | | *C.F.F.* Ee 3/3II 16501/02 | |
| *Current supply system* | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 20 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/ |
| *Number of motors* | 4 | | 4 | | 1 | |
| *Type of motors* | Series | | Series-Tandem | | Series | |
| *Number of armatures* | 1 | | 2 | | 1 | |
| *Number of commutators* | 1 | | 2 | | 1 | |
| *Characteristic values :* | | | | | | |
| *Continuous rating :* | | | | | | |
| *Power* (kW) | 153 | 153 | 460 | 500 | 465 | 46 |
| *Voltage* (V) | 1 500 | 1 500 | 376 | 460 | 670 | 67 |
| *Current* (A) | 111 | 111 | 1 350 | 1 350 | 750 | 75 |
| *Torque* (mkg) | 106 | 106 | ? | ? | 385 | 38 |
| *Rotating speed* (r.p.m.) | 1 400 | 1 400 | 1 350 | 1 460 | 1 170 | 1 17 |
| *One-hour rating :* | | | | | | |
| *Power* (kW) | 184 | 184 | 515 | 515 | 520 | 52 |
| *Voltage* (V) | 1 500 | 1 500 | 376 | 460 | 670 | 67 |
| *Current* (A) | 132 | 132 | 1 550 | 1 550 | 840 | 84 |
| *Torque* (mkg) | 137 | 137 | 410 | 410 | 445 | 44 |
| *Rotating speed* (r.p.m.) | 1 300 | 1 300 | 1 200 | 1 200 | 1 120 | 1 12 |
| *Maximum values :* | | | | | | |
| *Voltage* (V) | 1 800 | 1 800 | 441 | 588 | 900 | 90 |
| *Current* (A) | 224 | 224 | 2 170 | 2 170 | 1 450 | 1 45 |
| *Torque* (mkg) | 267 | 267 | 700 | 700 | 875 | 87 |
| *Rotating speed* (r.p.m.) | 2 250 | 2 250 | 1 615 | 1 615 | 1 900 | 1 90 |
| *Cooling* | self-ventilated | | separate | | separate | |
| *Flow of air at one-hour rating* ($m^3$/sec) | — | | 2.0 | | | |
| *Weight of motor* (kg) | 2 200 | | 3 910 | | 2 900 | |
| *Internal characteristics :* | | | | | | |
| *Insulation class* | B | | B | | B/F | |
| *Stator : Laminated* | no | | yes | | no | |
| *Main poles laminated* | yes | | yes | | yes | |
| *Interpoles laminated* | no | | yes | | yes | |
| *Compensation winding* | no | | yes | | yes | |
| *Number of poles* | 4 | | 2 × 12 | | 6 | |

## TOR CHARACTERISTICS

*Category* b
*A.C. - A.C.*

| *C.F.F.* Ee 3/3II 16503/04 | | *C.F.F.* Ee 3/3II 16505/06 | | *S.N.C.F.* BB 30001/02 | | *S.N.C.F.* BB 30003/04 | |
|---|---|---|---|---|---|---|---|
| 5 kV 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| 1 | | 1 | | 4 | | 2 | |
| Series 1 1 | | Series 1 1 | | Series 1 1 | | Series 1 1 | |
| 532 | 532 | 460 | 460 | 790 | 800 | 1 440 | 1 800 |
| 215 | 245 | 772 | 772 | 246 | 283 | 685 | 850 |
| 750 | 2 750 | 635 | 635 | 3 500 | 3 500 | 2 270 | 2 270 |
| 493 | 493 | 418 | 418 | 854 | 854 | 2 875 | 2 875 |
| 055 | 1 055 | 1 070 | 1 070 | 890 | 912 | 455 | 570 |
| 554 | 554 | 520 | 520 | 840 | 840 | 1 530 | 1 930 |
| 215 | 245 | 772 | 772 | 246 | 283 | 685 | 850 |
| 900 | 2 900 | 720 | 720 | 3 760 | 3 760 | 2 440 | 2 440 |
| 533 | 533 | 505 | 505 | 958 | 958 | 3 175 | 3 175 |
| 015 | 1 015 | 1 000 | 1 000 | 855 | 855 | 430 | 545 |
| 300 | 300 | 1 000 | 1 000 | 470 | 470 | — | 1 100 |
| 400 | 4 400 | 1 200 | 1 200 | 5 500 | 5 500 | — | 4 000 |
| 830 | 830 | 970 | 970 | 1 340 | 1 340 | — | 6 100 |
| 690 | 1 690 | 1 700 | 1 700 | 1 600 | 1 600 | — | 1 030 |
| separate | | separate | | separate | | separate | |
| 2.34 | | 1.75 | | 2.17 | | 6.0 | |
| 3 550 | | 3 160 | | 4 600 | | 6 930 | |
| B | | B | | B | | F | |
| yes | | no | | yes | | no | |
| yes | | yes | | yes | | yes | |
| yes | | yes | | yes | | yes | |
| yes | | no | | yes | | yes | |
| 16 | | 6 | | 20 | | 16 | |

TABLE 12. — TRACT

| | *Category* a *D.C. - D.C.* | | | | | |
|---|---|---|---|---|---|---|
| *Administration* *Type designation of unit* | *S.N.C.B.* « Benelux » | | *Oe.B.B.* E 1051.01 | | *C.F.F.* Ee 3/3II 16501/02 | |
| *Current supply system* | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 20 kV 50 c/s | 15 kV 16 2/3 c/s | 25 k 50 c/ |
| *Armature :* | | | | | | |
| *Diameter* . . . . . (mm) | 430 | | 780 | | 588 | |
| *Iron length* . . . . . (mm) | 425 | | 2 × 120 | | 254 | |
| *Number of slots* . . . . . | 46 | | 114 | | 72 | |
| *Conductors per slot* . . . . . | 14 | | 8 | | 2 × 8 | |
| *Type of winding* . . . . . | parallel | | parallel | | parallel Whittacke | |
| *Peripheral current density* (A/cm) | 314 | 314 | 480 | 480 | 435 | 43 |
| *Commutator :* | | | | | | |
| *Diameter* . . . . . (mm) | 365 | | 620 | | 370 | |
| *Length* . . . . . (mm) | 50 | | 190 | | 208 | |
| *Number of segments* . . . . | 322 | | 456 | | 288 | |
| *Commutator pitch* . . . (mm) | 3.56 | | 4.26 | | 4.03 | |
| *Maximum voltage between segments* (*Umax.p/k*) . . (V) | 22.4 | 22.4 | 11.6 | 15.4 | 18.8 | 18.8 |
| *Commutation factor :* | | | | | | |
| *A.D.* 1Fe . *n*/ *1 000. W* . . . | 75 | 75 | 54 | 54 | 73 | 73 |
| *Electromotive force of transformation at :* | | | | | | |
| *one-hour current* . . (V) | — | | 1.0 | 3.0 | — | |
| *maximum current* . . (V) | — | | ? | ? | — | |
| *Shunt losses at one-hour current* . . . . . (kW) | — | | ? | ? | about 2.0 | |
| *Dimensions of brushes* . . (mm) | (2 × 7.5) × 40 | | (2 × 6.25) × 45 | | (2 × 5.5) × 50 | |
| *Type of brushes* . . . . . | double brushes | | double brushes | | double brushes | |
| *Brush overlap* . . . . . | 4.2 | | 2.9 | | 2.7 | |
| *Number of brushes p. brush-holder* | 1 | | 4 | | 4 | |
| *Current density at one-hour rating* . . . . . (A/cm²) | 11.0 | 11.0 | 11.4 | 11.4 | 12.7 | 12.7 |
| *Cos φ at standstill* . . . . . | — | | ? | | — | |
| *at maximum speed* . . . . | — | | ? | | — | |
| *at 70 % of maximum speed* | — | | ? | | — | |
| *Air-gap of main pole* . . . (mm) | 2.67 | | 3.3 | | 6.0 | |
| *Air-gap of interpole* . . . (mm) | 10.0 | | 5.0 | | 11.5 | |
| *Special devices* . . . . . | — | | (1) | | (2), (4) | |

(1) The number of turns of the interpole windings changes with the frequency.
(2) Magnetic shunt of casing between main poles and interpoles.

**OR CHARACTERISTICS** (*continued*)

*Category* b
*A.C. - A.C.*

| *C.F.F.* Ee 3/3II 16503/04 | | *C.F.F.* Ee 3/3II 16505/06 | | *S.N.C.F.* BB 30001/02 | | *S.N.C.F.* BB 30003/04 | |
|---|---|---|---|---|---|---|---|
| 5 kV 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 Hz | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| 800 | | 590 | | 995 | | 1 536 : | |
| 380 | | 410 | | 410 | | 266 | |
| 144 | | 63 | | 180 | | 192 | |
| 6 | | 10 | | 6 | | 2 × 8 | |
| double parallel | | parallel | | double parallel | | parallel Whittacker | |
| 308 | 308 | 408 | 408 | 325 | 325 | 485 | 485 |
| 552 | | 500 | | 690 | | 960 | |
| 260 | | 199 | | 260 | | 200 | |
| 432 | | 315 | | 540 | | 768 | |
| 4.01 | | 5.0 | | 4.0 | | 3.92 | |
| 9.1 | 9.1 | 19.0 | 19.0 | 17.4 | 17.4 | — | 22.9 |
| 48 | 48 | 99 | 99 | 56 | 56 | 108 | 108 |
| 1.4 | 4.24 (3.95) | — | | 1.5 | 4.6 | — | |
| 1.6 | 4.9 (4.7) | — | | ? | ? | — | |
| 3.9 | 21.0 | approx. 3.6 | | ? | ? | — | |
| (2 × 5) × 50 | | (2 × 6) × 47 | | (2 × 5) × 50 | | (2 × 6) × 50 | |
| double brushes | | double brushes | | double brushes | | double brushes | |
| 2,5 | | 2,4 | | 2.5 | | 3 | |
| 5 | | 4 | | 5 | | 4 | |
| 14.5 | 14.5 | 10.6 | 10.6 | 15.0 | 15.0 | 12.7 | 12.7 |
| 0.36 | 0.21 | — | | ? | | — | |
| 0.99 | 0.99 | — | | ? | | — | |
| 0.99 | 0.92 | — | | ? | | — | |
| 2.5 | | 8.0 | | 2.5 | | 7.0 | |
| 3.0 | | 7.0 | | 2.5 | | 16.0 | |
| (3) | | (4) | | | | (2) and (4) | |

Ohmic shunt in parallel with the winding of the main poles for speeds lower than 5 km/h.
Ohmic shunt in parallel with the winding of the main poles.

TABLE 12. — TRACTI

| | | | | | | | | | | | Categ... L... |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Administration* | *F.S.* | | *S.N.C.F.* | | *S.N.C.F.* | | *S.N.C.F.* | | | | |
| *Type designation of unit* | Ale 840 | | CC 25001/09 | | BB 16500 | | BB 20004/05 | | | | |
| *Current supply system* | 3 000 V | 3 600 V Δ 16 2/3 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 3 000 V | 25 k... 50 c/... |
| *Number of motors* | 4 | | 6 | | 2 | | 2 | | |
| *Type of motors* | Series | | Series | | Series | | Series | | |
| *Number of armatures* | 1 | | 1 | | 1 | | 1 | | |
| *Number of commutators* | 1 | | 1 | | 1 | | 1 | | |
| *Characteristic values :* | | | | | | | | | |
| *Continuous rating :* | | | | | | | | | |
| *Power* (kW) | 136 | 136 | — | 510 | 700 | 1 290 | 1 070 | 1 070 | 1 06... |
| *Voltage* (V) | 1 500 | 1 500 | — | 250 | 455 | 1 100 | 1 500 | 1 500 | 1 50... |
| *Current* (A) | 100 | 100 | — | 2 640 | 800 | 1 250 | 760 | 760 | 76... |
| *Torque* (mkg) | 150 | 150 | — | 444 | 865 | 1 630 | 1 500 | 1 500 | 1 49... |
| *Rotating speed* (r.p.m.) | 880 | 880 | — | 1 110 | 395 | 770 | 690 | 690 | 69... |
| *One-hour rating :* | | | | | | | | | |
| *Power* (kW) | 172 | 172 | 50 | 530 | — | 1 330 | 1 130 | 1 130 | 1 12... |
| *Voltage* (V) | 1 500 | 1 500 | — | 250 | — | 1 100 | 1 500 | 1 500 | 1 50... |
| *Current* (A) | 127 | 127 | — | 2 780 | — | 1 285 | 800 | 800 | 80... |
| *Torque* (mkg) | 205 | 205 | 230 | 485 | — | 1 710 | 1 610 | 1 610 | 1 60... |
| *Rotating speed* (r.p.m.) | 815 | 815 | 180 | 1 060 | — | 775 | 680 | 680 | 68... |
| *Maximum values :* | | | | | | | | | |
| *Voltage* (V) | 1 800 | 1 800 | — | 265 | 550 | 1 200 | 1 800 | 1 800 | 1 50... |
| *Current* (A) | 215 | 215 | — | 4 500 | 1 000 | 1 900 | 950 | 950 | 95... |
| *Torque* (mkg) | 386 | 386 | — | 750 | 1 200 | 2 800 | 1 900 | 1 900 | — |
| *Rotating speed* (r.p.m.) | 1 700 | 1 700 | — | 1 635 | 660 | 1 420 | 1 500 | 1 500 | 1 50... |
| *Cooling* | self-ventilated | | separate | | separate | | separate | | |
| *Flow of air at one-hour rating* ($m^3$/sec) | — | | 1.5 | | 3.0 | | 3.65 | | |
| *Weight of motor* (kg) | 2 446 | | 3 000 | | 4 680 | | 5 500 | | |
| *Internal characteristics :* | | | | | | | | | |
| *Insulation class* | B | | B | | H | | H | | |
| *Stator : Laminated* | no | | yes | | yes | | no | | |
| *Main poles laminated* | yes | | yes | | yes | | yes | | |
| *Interpoles laminated* | yes | | yes | | yes | | yes | | |
| *Compensation winding* | no | | yes | | no | | yes | | |
| *Number of poles* | 4 | | 16 | | 8 | | 6 | | |

**TOR CHARACTERISTICS** (*continued*)

| *C.F.F.* Ae 4/6III 10851 | | | *C.F.F.* TEE II | | | | *C.F.F.* TEE II (1st project) | | | | *C.F.F.* Ee 3/3IV 16551/60 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| 4 | | | 4 | | | | 8 | | | | 2 | | | |
| Series | | | Series | | | | Series | | | | Series/separate excitation | | | |
| 1 | | | 1 | | | | 1 | | | | 1 | | | |
| 1 | | | 1 | | | | 1 | | | | 1 | | | |
| 380 | 380 | 380 | 512 | 512 | 537 | 512 | 320 | 320 | 270 | 202 | 172 | 172 | 172 | 172 |
| 750 | 750 | 750 | 1 500 | 1 500 | 1 500 | 1 500 | 375 | 375 | 332 | 270 | 1 500 | 1 500 | 1 500 | 1 500 |
| 550 | 550 | 550 | 360 | 360 | 360 | 360 | 950 | 950 | 920 | 950 | 123 | 123 | 123 | 123 |
| 214 | 214 | 214 | 476 | 476 | 486 | 476 | 252 | 252 | 229 | 122 | 190 | 190 | 190 | 190 |
| 730 | 1 730 | 1 730 | 1 045 | 1 045 | 1 065 | 1 045 | 1 240 | 1 240 | 1 150 | 1 620 | 885 | 885 | 885 | 885 |
| 435 | 435 | 435 | 568 | 568 | 594 | 568 | 375 | 375 | 315 | 236 | 197 | 197 | 197 | 197 |
| 750 | 750 | 750 | 1 500 | 1 500 | 1 500 | 1 500 | 375 | 375 | 332 | 270 | 1 500 | 1 500 | 1 500 | 1 500 |
| 525 | 625 | 625 | 400 | 400 | 400 | 400 | 1 120 | 1 120 | 1 080 | 1 120 | 142 | 142 | 142 | 142 |
| 258 | 258 | 258 | 560 | 560 | 567 | 560 | 341 | 341 | 304 | 174 | 230 | 230 | 230 | 230 |
| 550 | 1 650 | 1 650 | 986 | 986 | 1 015 | 986 | 1 070 | 1 070 | 1 010 | 1 320 | 840 | 840 | 840 | 840 |
| 000 | 1 000 | 1 000 | 2 000 | 2 000 | 1 800 | 1 800 | 450 | 450 | 418 | 334 | — | — | — | — |
| 950 | 950 | 950 | 650 | 650 | 600 | 600 | 1 330 | 1 330 | 1 700 | 1 700 | 258 | 258 | 258 | 258 |
| — | — | — | 1 130 | 1 130 | 1 030 | 1 010 | 455 | 455 | 565 | 374 | 480 | 480 | 480 | 480 |
| 200 | 2 200 | 2 200 | 1 860 | 1 860 | 1 860 | 1 860 | 1 870 | 1 870 | 1 870 | 1 870 | 2 135 | 2 135 | 2 135 | 2 153 |
| self-ventilated | | | separate | | | | self-ventilated | | | | separate | | | |
| — | | | 1.67 | | | | — | | | | 1.0 | | | |
| — | | | 3 450 | | | | 2 200 | | | | 2 200 | | | |
| B | | | B | | | | B | | | | B | | | |
| no | | | yes | | | | yes | | | | no | | | |
| yes | | | yes | | | | yes | | | | yes | | | |
| yes | | | yes | | | | yes | | | | yes | | | |
| no | | | no | | | | yes | | | | no | | | |
| 6 | | | 4 | | | | 10 | | | | 4 | | | |

TABLE 12. — TRACT

| | | | | | | | | | | | | Catego D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Administration* | *F.S.* | | *S.N.C.F.* | | *S.N.C.F.* | | *S.N.C.F.* | | | | | |
| *Type designation of unit* | Ale 840 | | CC 25001/09 | | BB 16500 | | BB 20004/05 | | | | | |
| *Current supply system* | 3 000 V | 3 600 V Δ 16 2/3 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 25 kV 50 c/s | 1 500 V | 3 000 V | 25 kV 50 c/ |
| *Armature :* | | | | | | | | | |
| *Diameter* . . . . . (mm) | 500 | | 800 | | 930 | | 800 | | |
| *Iron length* . . . . . (mm) | 310 | | 380 | | 280 | | 360 | | |
| *Number of slots* . . . . . | 45 | | 144 | | 116 | | 93 | | |
| *Conductors per slot* . . . . . | 14 | | 6 | | 8 | | 12 | | |
| *Type of winding* . . . . . | series | | double parallel | | parallel twisted | | parallel | | |
| *Peripheral current density* (A/cm) | 200 | 200 | — | 299 | — | 510 | 595 | 595 | 59 |
| *Commutator :* | | | | | | | | | |
| *Diameter* . . . . . (mm) | 445 | | 550 | | 672 | | 690 | | |
| *Length* . . . . . (mm) | 138 | | 258 | | 142 | | 130 | | |
| *Number of segments* . . . . . | 315 | | 432 | | 464 | | 558 | | |
| *Commutator pitch* . . . (mm) | 4.44 | | 4.0 | | 4.55 | | 3.88 | | |
| *Maximum voltage between segments (Umax.p/k)* . . (V) | 22.8 | 22.8 | — | 9.8 | 9.5 | 20.7 | 19.4 | 19.4 | 16. |
| *Commutatoion factor :* | | | | | | | | | |
| *A.D.* 1Fe . *n/1 000* . *W* . . . | 25 | 25 | — | 48 | — | 100 | 116 | 116 | 116 |
| *Electromotive force of transformation at :* | | | | | | | | | |
| *one-hour current* . . (V) | — | | — | 4.3 | — | — | — | | — |
| *maximum current* . . (V) | — | | — | 7.0 | — | — | — | | — |
| *Shunt losses at one-hour current* . . . . . (kW) | — | | — | — | — | 19.25 | — | | — |
| *Dimensions of brushes* . . (mm) | 12 × 40 | | (2 × 5) × 50 | | (2×8.5) × 42 | | (2 × 10) × 40 | | — |
| *Type of brushes* . . . . . | monobloc | | triple brushes | | doub. brush. | | double brushes | | — |
| *Brush overlap* . . . . . | 2.7 | | 2.8 | | 3.7 | | 5.4 | | |
| *Number of brushes p. brush-holder* | 3 | | 5 | | 3 | | 3 | | |
| *Current density at one-hour rating* . . . . . (A/cm²) | 8.8 | 8.8 | | 13.9 | 15.0 | 15.0 | 11.1 | 11.1 | 11. |
| *Cos φ at standstill* . . . . . | | | | | | | | | |
| *at maximum speed* . . . . | — | | — | 0.95 | — | | — | | |
| *at 70 % of maximum speed* | — | | — | 0.89 | — | | — | | |
| *Air-gap of main pole* . . . (mm) | 5.0 | | 2.5 | | 5.5 | | 5.0 | | |
| *Air-gap of interpole* . . . (mm) | 6.25 | | 3.0 | | 8.0 | | 7.5 | | |
| *Special devices* . . . . . | | | | | (2) | | | | |

(1) Magnetic shunt of casing between main poles and interpoles.
(2) Ohmic shunt in parallel with the winding of the main poles.

**TOR CHARACTERISTICS** (*continued*)

| *C.F.F.* Ae 4/6[III] 10851 | | | *C.F.F.* TEE II | | | | *C.F.F.* TEE II (1st project) | | | | *C.F.F.* Ee 3/3[IV] 16551/60 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 600 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| 538 | | | 620 | | | | 660 | | | | 465 | | | |
| 254 | | | 340 | | | | 280 | | | | 360 | | | |
| 75 | | | 66 | | | | 125 | | | | 49 | | | |
| 8 | | | 12 | | | | 6 | | | | 14 | | | |
| parallel | | | parallel | | | | parallel | | | | series | | | |
| 368 | 368 | 368 | 406 | 406 | 406 | 406 | 405 | 405 | 390 | 405 | 334 | 334 | 334 | 334 |
| 320 | | | 540 | | | | 560 | | | | 435 | | | |
| 84 | | | 128 | | | | 160 | | | | 87 | | | |
| 300 | | | 396 | | | | 375 | | | | 343 | | | |
| 3.36 | | | 4.28 | | | | 4.68 | | | | 4.0 | | | |
| 0.0 | 20.0 | 20.0 | 20.2 | 20.2 | 18.2 | 18.2 | 11.4 | 11.4 | 10.1 | 8.1 | | | | |
| 3 | 83 | 83 | 84 | 84 | 86 | 84 | 81 | 81 | 74 | 98 | 47 | 47 | 47 | 47 |
| — | | | | | | 3.6 | — | — | 2.46 | 4.16 | — | | | |
| — | | | | | | — | — | — | 2.96 | 6.10 | — | | | |
| (2 × 10) × 40 | | | (2 × 7.5) × 40 | | | | (2 × 5) × 50 | | | | (2 × 6) × 40 | | | |
| double brushes | | | double brushes | | | | double brushes | | | | — | | | |
| 6 | | | 3.5 | | | | 2.14 | | | | 3.0 | | | |
| 2 | | | 3 | | | | 3 | | | | 2 | | | |
| 3.0 | 13.0 | 13.0 | 11.1 | 11.1 | 11.1 | 11.1 | 14.9 | 14.9 | 14.4 | 14.9 | 7.4 | 7.4 | 7.4 | 7.4 |
| | | | | | | | | | 0.32 | 0.27 | | | | |
| — | | | — | | | | — | — | 0.99 | 0.96 | — | | | |
| — | | | — | | | | — | — | 0.98 | 0.88 | — | | | |
| 6.0 | | | 13.2 | | | | 3.5 | | | | 9.0 | | | |
| 9.0 | | | 10.0 | | | | 4 | | | | 9.0 | | | |
| (1) and (2) | | | (3) | | | | — | | | | (2) | | | |

Combined ohmic shunt in parallel with the windings of the main poles and interpoles.

As the magnetic field of the auxiliary poles cannot be the same for 16 2/3 cycles and 50 cycles, the degree of ohmic and inductive shunting has to be changed when passing from one supply system to the other. It is not the degree of inductive shunting on the E. 1051.01 locomotive of the OeBB which is changed, but the number of turns of the auxiliary poles. The change of shunting takes place through the current selecting device.

Undulatory current motors are, as regards their characteristics, like D.C. motors. From the point of view of design, they differ from D.C. motors because of their laminated main and auxiliary poles. According to the degree of undulation of the supply current, even the stator may be laminated. In certain cases, the stators are shunted magnetically by the introduction of additional stampings (locomotives BB 30003/4 of the SNCF, Ee 3/II 16501/2 and Ae 4/6III 10851 of the CFF). High power motors have to have a special winding of the armatures, for example the Whittacker windings with twisted lap joint (locomotives BB 16500, BB 30003/4 of the SNCF and Ee 3/3II 16501/2 of the CFF). In certain cases, ohmic shunts have to be provided for the main poles and possibly for the auxiliary poles. Such a design makes it possible to build undulatory current motors for powers up to 2 000 kW and the result is a very favourable weight power unit ratio. The supply of the engine by current of different frequencies does not involve any special measures in the case of undulatory current motors.

3. *D.C. and A.C. units.*

These can be fitted with A.C. series motors or undulatory current series motors. Both these types of motors can be supplied equally well with D.C. as well as A.C. or undulatory current. For the moment, the solution of single-phase motors has not yet been adopted and all the machines are equipped with undulatory current motors. This solution practically is the only one possible as the motors must be designed for 1 500 V or at least 750 V if they are to run on D.C.; and it is precisely these values which result in difficulties in the case of an A.C. supply, in particular for 50 cycles, but not for the supply of undulatory current. As the nominal voltage of 50 cycle A.C. motors should not exceed 400 V, such motors can only be used if there are four or even eight in series in order to supply the unit with D.C. at 1 500 or 3 000 V. In this connection, it may be of interest to point out that the first designs for the TEE sets of the CFF provided for eight motors in series at 375 V supplied with D.C. or A.C. This solution was not given up for reasons to do with the electrical equipment but on account of the mechanical part.

## F. Electric brake.

Most single-current units have no electric brake, and this is also true of the polycurrent units. From the operating point of view, the same reasons may lead to the fitting of the electric brake in the case of both types of units. From the technical point of view, designing an electric brake for multi-current units presents greater difficulties. One of these is due to the fact that the relatively complicated equipment of a polycurrent unit will become even bulkier, as the addition of an electric brake is more or less the same as adding an additional operating regime. This is the reason why the rheostatic brake is advantageous; this is the brake requiring the fewest special equipments and the starting resistances can be used as braking resistances. The rheostatic brake is the only electric brake which can be used independently of the supply system. The TEE sets and the four-system shunting locomotives of the CFF will be equipped with such brakes. In practice, regenerative brakes can only be used with a single type of current. The CC 25001/9 locomotives of the SNCF are fitted with such brakes. The fact that this brake cannot be used on the sections with a D.C. supply will not be a drawback, as the supply of D.C. to these locomotives is only a secondary supply.

## G. Supply to the auxiliary equipment.

The supply for the auxiliary equipment is made by various methods. These depend, on the one hand, on the supply system, and on the other, on the custom on the different railways. The solutions adopted are collected together in Table 13.

### 1. *D.C. units.*

The general tendency as regards the construction of D.C. units is to have as few auxiliary motors as possible, as it is difficult to build small motors for 1 500 V or 3 000 V. For this reason, the traction motors are self-ventilating, as are, if possible, the starting resistances. There only remains the compressor and possibly a small converter group for charging the battery and other applications. In the case of two-current units, the auxiliary motors have to have two collectors so that either 1 500 V or 3 000 V current can be used. In the case of the « Benelux » SNCB/NS rakes, there is only one motor-compressor-dynamo group.

### 2. *A.C. units.*

The auxiliary motors of such machines can be supplied either directly from the transformer, or through rectifiers. If the difference between the two supply voltages is not too great, it is not necessary to provide two auxiliary connections to the transformer. This is the solution used on the E. 1051.01 locomotives of the OeBB, where the auxiliary motors are supplied with 98 V 16 2/3 cycles and 131 V 50 cycles A.C.

On the other bi-frequency locomotives, where the auxiliary installations are all supplied through rectifiers (locomotives Ee 3/3II 16501/6 of the CFF), or partly through rectifiers and partly directly from the transformer (locomotives BB 30003/4 of the SNCF), the auxiliary voltages are kept at the same values.

### 3. *D.C. and A.C. units.*

With such units, there are generally engines or auxiliary equipment which must be able to work with all the different systems of supply to the unit. These are, for example, the compressor, the battery charging equipment, and, possibly, the ventilation of the traction motors. Other auxiliary motors are only required when the unit is running on A.C. These are the equipments for cooling the transformer, the rectifiers and possibly the smoothing-out self inductance coils. When running on D.C. the starting resistances sometimes have forced ventilation. The motors driving the fans are everywhere connected in parallel to one section of these resistances.

Certain units are fitted with a converter group which is supplied from a three-phase system. In the case of the CC 25001/9 locomotives of the SNCF, an Arno group is used. The TEE sets of the CFF will be equipped with a group driven by a motor with a double collector, supplied either with 1 500 V or 3 000 V D.C. and with A.C. converted into undulatory current of 1 500 V by means of semi-conductor rectifiers.

## H. Train heating and lighting.

In the case of D.C. vehicles, the train heating circuit can only be directly connected to the catenary. In other words, the heating equipment of the coaches hauled by a locomotive using 1 500 V or 3 000 V D.C. must be able to run on these two voltages. In the case of a 15 kV 16 2/3 cycle and 25 kV 50 cycle locomotive, it is easy to keep the same supply voltage for the heating when changing from one system to another; it is only necessary to provide two tappings for the purpose on the locomotive transformer, and there only remains the difference in frequency. In the case of D.C. and A.C. locomotives, the difference in voltage and the difference in frequency are interdependent. There is no difficulty in the case of the coaches in international service, as these must in any case be equipped with

TABLE 13. — SUP

| | *Category* a *D.C. - D.C.* | | *Categ* *A* | |
|---|---|---|---|---|
| *Administration* *Type designation of unit* | *S.N.C.B.* « Benelux » | | *Oe.B.B.* E 1051.01 | |
| *Current supply systems* | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 20 kV 50 c/s |
| *Auxiliaries (excluding those fed by the battery)* | 1 compressor | | 1 compressor 1 oil pump 2 blowers 1 motor/generator | |
| *Total power required for auxiliaries* . (kVA) | 27 | | approx. 60 | |
| *Current supply for auxiliaries* . . . . . | 1 500 V— | 3 000 V— | 98 V~ | 131 V~ |
| *Types of motors driving the auxiliaries* . . . . | series 2 commutators | | single-phase commutator | |
| *Source of current supply for the auxiliaries* . . . | catenary | | transformer | |
| *Set* . . . . . | motor/ compressor/ dynamo | | — | |
| *Tapping for external feed* . . . . . | — | | 100 V, 16 2/3 c/s | |
| *Earth connection of auxiliaries* . . . . . | direct | | direct | |
| *Battery charging* . . . . . | dynamo | | dynamo | |
| *Type of batteries* . . . . . | nickel-cadmium | | alkaline | |
| *Characteristics : capacity* . . . . . (Ah) | 120 | | 60 | |
| *voltage* . . . . . (V) | — | | 24 | |
| *maximum current : charge* . . . . . (A) | — | | — | |
| *discharge* . . . . . (A) | — | | — | |
| *Train heating : voltage* . . . . . (V) | 1 500 | 3 000 | 800 | 1 000 |
| *maximum amperage* . . . (A) | 36.4 | 18.2 | 400 | 400 |
| *Cab heating : voltage* . . . . . (V) | 1 500 | 3 000 | 98 | 113 |
| *amperage* . . . . . (A) | — | — | 40 | 40 |

| *C.F.F.* Ee 3/3II 16501/06 | |
|---|---|
| 15 kV 16 2/3 c/s | 25 k 50 c |
| 1 compressor 2-3 blowers | |
| — | |
| 230 V | |
| series | |
| transformer/ auxiliary rectifier | |
| — | |
| 220 V, 16 2/3 c/s | |
| direct | |
| rectifier | |
| lead | |
| 90 | |
| 36 | |
| 25 | |
| 25 | |
| — | — |
| — | — |
| 220 | 22 |
| — | — |

## AUXILIARIES

| | | | | *Category* c *D.C. - A.C.* | | | |
|---|---|---|---|---|---|---|---|
| *S.N.C.F.* BB 30001/02 | | *S.N.C.F.* BB 30003/04 | | *F.S.* Ale 840 | | *S.N.C.F.* CC 25001/09 | |
| kV /3 c/s | 25 kV 50 c/s | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 3 000 V | 3 600 V Δ 16 2/3 c/s | 1 500 V | 25 kV 50 c/s |
| 1 compressor<br>1 oil pump<br>3 blowers | | 1 compressor<br>1 oil pump<br>5 blowers | | 2 compressors<br>—<br>— | <br>1 compressor<br>4 blowers | 1 compressor<br>3 blowers<br>1 oil pump | |
| 55 | 61 | 55 | 58 | — | — | — | 72 |
| V~<br>—<br>— | 380 V~<br>235 V~<br>190 V~ | 140 V~<br>170 V undulatory | 235 V~<br>— | 3 000 V<br>—<br>— | 3 000 V—<br>220 V~<br>24 V~ | 380 V 50 c/s three-phase<br>—<br>— | |
| e-phase commutator<br>two-phase capacitor | | single-phase commutator and D.C. | | D.C. and single-phase commutator | | asynchronous three-phase squirrel-cage | |
| transformer | | transformer direct or rectified | | catenary | transformer/ (rectifiers) | converter/ Arno set | transformer/ Arno set |
| — | | — | | motor/compressor/dynamo | | Arno/dynamo | |
| — | | — | | 24 V— | | — | |
| by earth relay | | by earth relay | | direct | | direct | |
| rectifier | | rectifier | | dynamo | | dynamo | |
| nickel-cadmium | | nickel-cadmium | | lead | | nickel-cadmium | |
| 80 | | 80 | | 130 | | 80 | |
| 72 | | 72 | | 24 | | 72 | |
| 16 | | 16 | | 30 | | 16 | |
| 16 | | 16 | | 30 | | 16 | |
| 00/600 | 1 500/1 000 | 1 000/600 | 1 500/1 000 | 3 000 | 3 000 | 1 500 | 1 500 |
| 560 | 560 | 560 | 560 | 17 | 17 | 560 | 560 |
| 400 | 420 | 420 | 420 | 3 000 | 3 000 | 380 | 380 |
| 21 | 21 | 21 | 21 | — | — | — | — |

TABLE 13. — SUP

| *Administration* / *Type designation of unit* | *S.N.C.F.* BB 16500 | | *S.N.C.F.* BB 20004/05 | | |
|---|---|---|---|---|---|
| *Current supply system* | 1 500 V | 25 kV 50 c/s | 1 500 V | 3 000 V | 25 kV 50 c/s |
| *Auxiliaries (excluding those fed by the battery)* | 1 compressor 2 blowers | | 1 compressor 2 blowers | | |
| | — | 1 oil pump 1 water pump | — | | blowe 1 oil pu 1 water p |
| *Total power required for auxiliaries* . . (kVA) | 14 | 47 | — | | — |
| *Current supply for auxiliaries* . . . . . | 1 500 V | 1 500 V | 1 500 V | 3 000 V | 1 500 V |
| | — | 130 V | — | — | 380 V |
| | — | 100 V | — | — | — |
| | — | 390 V~ . | | | |
| *Types of motors driving the auxiliaries* . . . . | D.C. | | D.C. | | |
| | — | D.C. two-phase capacitor | — | | two-pha capacit |
| *Source of current supply for the auxiliaries* . . | catenary | transformer/ (possibly rectifiers) | catenary | | transform (rectifie |
| *Set* . . . . . | — | | — | | |
| *Tapping for external feed* . . . . . | — | | — | | |
| *Earth connection of auxiliaries* . . . . . | direct | | direct | | direct an |
| | — | by earth relay | | | by earth r |
| *Battery charging* . . . . . | by resistance | rectifiers | by the current flowing through the traction motor blowers | | |
| *Type of batteries* . . . . . | nickel-cadmium | | nickel-cadmium | | |
| *Characteristics : capacity* . . . . . (Ah) | 80 | | 80 | | |
| *voltage* . . . . . (V) | 72 | | 72 | | |
| *maximum current : charge* . . . . . (A) | 16 | | 16 | | |
| *discharge* . . . . . (A) | 16 | | 16 | | |
| *Train heating : voltage* . . . . . (V) | 1 500 | 1 500 | 1 500 | 3 000 | 1 500 |
| *maximum amperage* . . (A) | 550 | 550 | 550 | 550 | 550 |
| *Cab heating : voltage* . . . . . (V) | 1 500 | 1 500 | 1 500 | 3 000 | 1 500 |
| *amperage* . . . . . (A) | 2 | 2 | 2.7 | 1.3 | 2. |

**UXILIARIES** (*continued*)

*Category* c
*D.C. - A.C.*

| *C.F.F.* Ae 4/6III 10851 | | | *C.F.F.* TEE II | | | | *C.F.F.* Ee 3/3IV 16551/60 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 00 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s | 1 500 V | 3 000 V | 15 kV 16 2/3 c/s | 25 kV 50 c/s |
| 1 compressor 4 blowers | | | 1 compressor various blowers | | | | 1 compressor various blowers | | | |
| — | blowers | | — | | 1 oil pump | | — | | blowers | |
| — | — | | approx. 180 | | | | — | | | |
| V | 155 V undulatory | | 380/220 V, 50 c/s three-phase | | | | 1 500 V 220 V— | 3 000 V 220 V— | 1 500 V 220 V | 1 500 V 220 V |
| — | — | | — | | | | | | | |
| D.C. | | | asynchronous squirrel-cage | | | | D.C. (compressor and converter motors with two commutators) | | | |
| erter | transformer/ rectifier | | converter | | transformer/ rectifier/ converter | | converter | | transformer/ rectifier/ (converter) | |
| tor/ erator | — | | twin motor / generator three-phase | | | | twin motor / generator / dynamo / blowers | | | |
| motor / dynamo | | | | | | | | | | |
| 220 V, 16 2/3 c/s | | | 380/220 V, 50 c/s three-phase | | | | — | | — | |
| direct | | | — | | | | direct | | | |
| dynamo | | | converter - rectifier | | | | dynamo | | | |
| lead | | | lead | | | | lead | | | |
| 90 | | | 2 × 240 | | | | 90 | | | |
| 36 | | | 120 | | | | 36 | | | |
| 25 | | | 100 | | | | 25 | | | |
| 25 | | | 100 | | | | 25 | | | |
| 500 1 000 1 500 | | | 1 500 V 80 | 3 000 V 40 | 1 500 V 80 | 1 500 V 80 | — — | — — | — — | — — |
| 155 155 155 | | | 220 V, 50 c/s | | | | 220 V | | | |
| — — — | | | — | | | | — | | | |

a system of heating that can run on different voltages and frequencies. For heating the passenger compartments of the rail motor coaches or motor sets, the same problem arises so long as the heating is not run off an independent supply. This solution is not a very good one, because the system must have a high capacity, which will be not completely used during the summer. This drawback disappears if the vehicle is equipped with air conditioning.

The lighting of a multi-current locomotive does not give rise to any problems, because the lamps are run off a battery. The same applies in the case of the lighting of the passenger compartments of rail motor coaches or motor sets when this is run on a battery. If use is made of fluorescent tubes, these cannot be supplied from an independent system which takes its supply from the catenary, as such a system would be dead when the pantographs were lowered.

### 1. Controls.

The controls for the equipment of a polycurrent locomotive do not give rise to any special problems. Electric or electropneumatic control is made use of everywhere, as is the practice on single-current units. The design of the driving compartments is the same for polycurrent units as for other motor units. It is only necessary to provide a few additional controls, for example a pantograph selector or a control for the selector device for the supply system. All the driving compartments of polycurrent locomotives are equipped with a single controller for regulating the speed, as well as possibly a shunt controller.

## IV. CONCLUSIONS.

### A. Present position.

The stock of polycurrent units at the present time consists of line locomotives, rail motor coaches and shunting locomotives. The fact that in Europe there are at least five different supply systems on the main lines of the railways is responsible for these polycurrent units. These units have been put into service in the large stations where there are two different supply systems and on the main lines with different systems of electrification.

At the present time, only units for two systems of supply are in service. There are two reasons for this. On the one hand, there are no stations at the present time which are electrified with more than two supply currents; and on the other hand, long sections of the international lines have only recently been equipped with a catenary.

As the construction of polycurrent units raises a great many problems, the first realisations were made as simple as possible. For this reason, in these first vehicles, one of the two supply currents is converted to the other. A few later units have been built for two different systems of A.C. and others for D.C. of two different voltages.

The conversion of one supply to another type does not give rise to any special problems as regards the motor equipment; it is merely necessary to install additional equipment. On the other hand, the supply of a polycurrent unit with two different voltages of D.C. or with A.C. of different frequencies necessitates special precautions for the motor equipment.

### B. Future evolution.

More and more it appears desirable to have polycurrent units which can be supplied by three or four systems of current. To meet this desire, TEE sets are being built for four different currents, line locomotives for three, and shunting locomotives for four, without mentioning other bi-current vehicles. Such a development is understandable as soon all the great international lines with heavy traffic will be electrified. The evolution of technique will also make such realisations possible. Scien-

tific research has resulted in many improvements in the design and construction of traction motors, and great progress is being made in connection with rectifiers. Progress has also been made in the use of insulating materials.

The short time on which experience with polycurrent units in service is based and the diversity of the equipment used on the machines and those under construction, make it impossible to state which of the different solutions is the best, so that no recommendations for future realisations can be put forward.

In the future, the use of polycurrent units is certain to increase, on the one hand, at places where there is a change from one supply system to another, and on the other hand, in the case of long distance passenger services, where they will replace steam engines to an every increasing extent.

[ 625 .213 ]

# A new application for an electronic analogue computer : the study and checking of the suspension of vehicles,

by A. Chiesa and S. Franceschetti,

(*Rivista di Ingegneria*, No. 8, August 1958.)

## Introduction.

An electronic analogue computer, as one knows, is composed of an assembly of parts (operational units) which carry out the principal algebraic and differential operations of the analysis, not by means of mathematical functions but by electrical voltages which vary in the same way as the mathematical functions being studied and which can be re-converted into the latter with the aid of appropriate scaling factors.

An equation, or set of differential equations, is solved by connecting together various operational units for summation and integration, in an appropriate manner.

The name of analogue computer is derived from the fact that the electrical circuits used for the solution obey the same laws as those governing the physical system under study, irrespective of its type : mechanical, hydraulic, thermic or electrical.

The degree of complexity of the problems which can be handled by the computer is determined by the number of operational units available. For example, in a computer built by a firm in Milano (fig. 1), twenty integrating units and forty summation units are available. It is possible, therefore, to solve differential systems of up to the twentieth order. This maximum capacity of the computer can be employed in different ways. For example, it is possible to solve simultaneously several differential systems whose sum of orders does not exceed twenty.

## Analogue calculation of the suspension of vehicles.

A typical case which can be handled by analogue computer is that of a model with six degrees of freedom which simulates, to a first approximation, the vertical longitudinal section of a railway carriage (fig. 2). The larger mass M represents the coachwork of the carriage; the two masses $m_1$ and $m_2$ represent the masses of the bogies; the values of stiffness and viscosity $k$, $c$ and K, C relate to the primary and secondary springing systems respectively.

The fundamental advantages obtained by calculation with an electronic analogue computer compared with mathematical analysis are, in general and in the particular case being studied, essentially three in number.

The first advantage lies in the possibility of dealing with a very complex mathematical system, or else as in the case of mechanics, the model formed by sets of masses, springs and shock absorbers, having several degrees of freedom. It is known, on the other hand, that it is only possible to handle models with at most one or with difficulty two degrees of freedom by means of mathematical analysis. This enables the physical system to be studied in its entirety instead of by means of excessively partial theoretical models, often leading to situations which are unacceptably removed from reality, as has to be done when a problem is analysed mathematically.

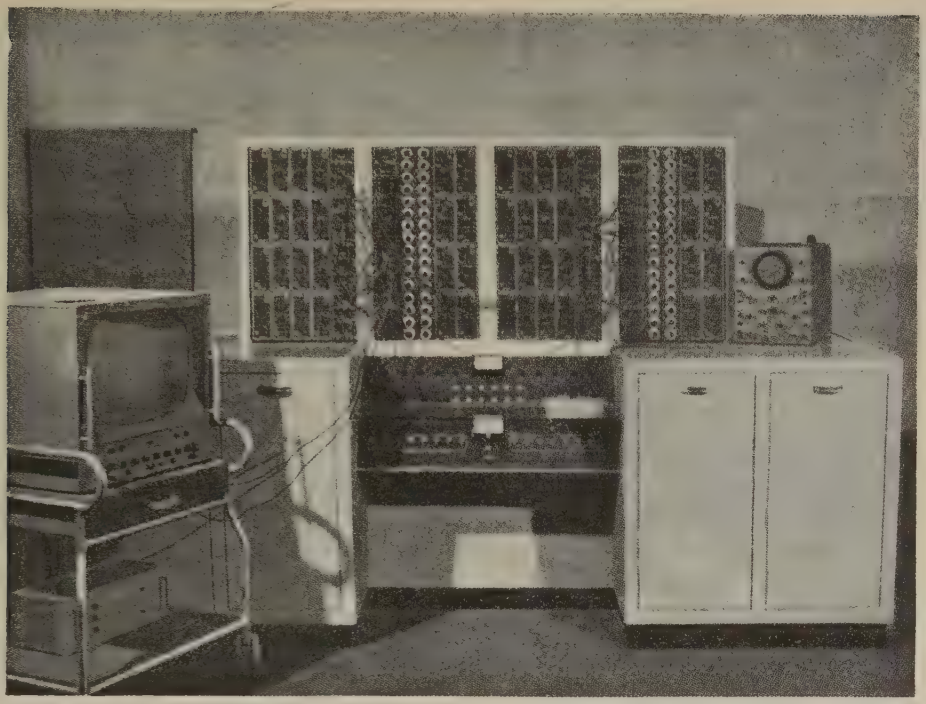


Fig. 1. — Electronic analogue computer built at the laboratories of Pirelli Co. Ltd., Milan.

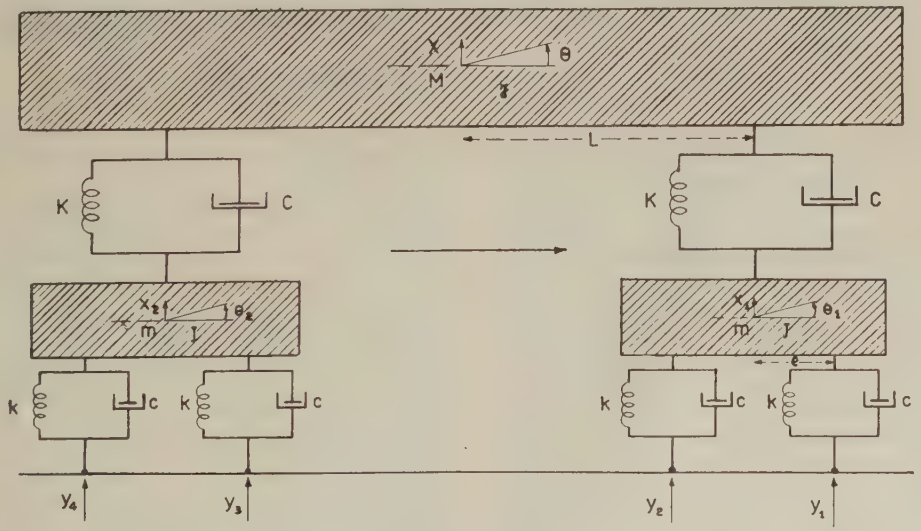



Fig. 2. — Model with six degrees of freedom used in the study of the behaviour of rotation and longitudinal travel of a railway carriage.

Moreover, the computer provides at the same time, not only the variations of the unknown quantities, but also many other derivative values which might concern the problem under study.

In fact, the six principal unknown quantities of the system are the motions of rotation and translation $\theta$ and X of the coachwork and the bogies, but it is very easy to obtain at the same time the variations of many other measurements, such as the speed or acceleration of these motions, the stresses transmitted, the corresponding travel of the springing, and several other values.

The second advantage is the possibility of dealing with non-linear elements, in other words, in the case of the mechanical example under consideration, the springs and shock absorbers having characteristics differing, even to a considerable extent, from the case of simple proportionality.

This fact is of considerable importance as the elements of real mechanical systems often behave in a manner which is somewhat removed from linearity pure and simple, as for example, two different slopes for positive and negative values of characteristics, or even parabolic or hyperbolic shapes or variations within limited travel devices. Analogy alone enables one to take account of all these different cases of non-linearity and thus arrive by theoretical study at a result which is very close to reality.

The third advantage is the power to deal with exciting functions of totally arbitrary behaviour, whereas with analytical calculations it is only possible to solve the equation or differential system in the case of a small number of exciting functions, mainly restricted to sinusoidal and stepped functions.

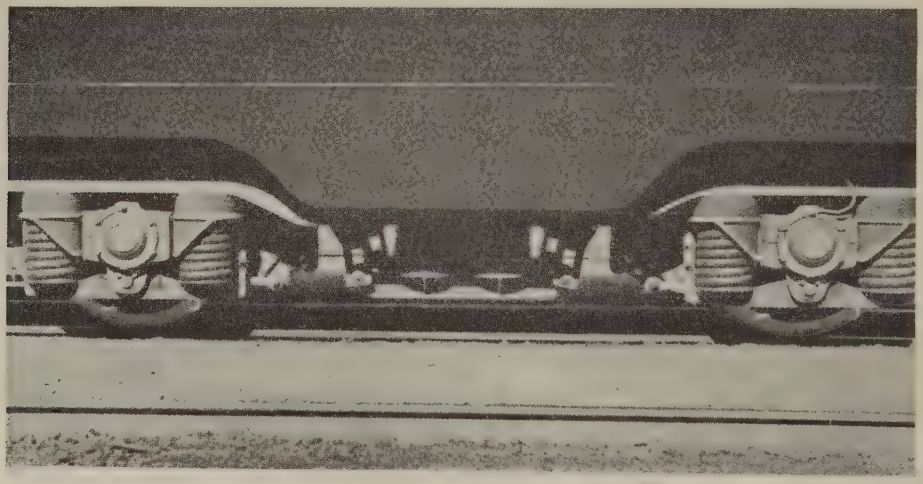


Fig. 3. — Suspension of the railway carriage (traction coach of the T.E.E.) corresponding to the model in figure 2.

On the other hand, with the aid of an electronic computer, no difficulty is encountered in the study of the behaviour of the planned system incorporating any kind of exciting functions. It is sufficient to transmit signals to the computer with the same variations as the desired exciting functions. Electric signals of arbitrary form can be obtained by different methods. One of the simplest consists of drawing the arbitrary profile of the function in black and white on a film and passing the film at a pre-determined speed through a projector with a photo-electric cell.

It is thus possible to study the behaviour of the model of the railway carriage in question whilst it is travelling on a track having a completely arbitrary profile and at any speed. The profile of the track has in fact been recorded on the film and it is sent to the computer as an exciting function of the system.

To these three fundamental advantages must evidently be added that concerning the simplicity and very great rapidity of calculation which enables any element of the model to be varied, e.g. the stiffness of any spring and the viscosity of any type of shock absorber, or else to vary any one of the imposed conditions such as the profile of the track or the speed, and to see immediately the consequences on all the different mechanical measurements concerning the model.

## Application of the analogue computer to a practical example of suspension.

The use of the computer in the study of a model of the type described has proved particularly useful in a typical case: that of a projected railway carriage with primary and secondary rubber suspension. The characteristics of this solution, in fact, made it difficult if not impossible to handle mechanically, precisely because of the operation of non-linear elements with respect to stiffness and viscosity.

The diagram of the suspension system (fig. 3) corresponds exactly to the model of figure 2. An interesting parallel occurred, therefore, between a completely new, but practical, development (that of the Trans-Europ-Express of Italian design) and its reproduction as a model for the analogue computer.

The means of suspension employed were a mixture of rubber and steel. The load-deflection diagram showed a completely non-linear relationship, having a double change of slope (fig. 4) and producing a considerable damping effect, of a viscous type, as a function of the speed of relative motion.

Fortunately, the diagram was not further complicated, from the mathematical point of view, by the presence of hydraulic shock absorbers as the springs employed made it possible to omit them.

The practical trials and analogue calculations have been repeated for different suspension characteristics and for various speeds. For example, the results obtained by the computer for one of the cases examined are shown in figure 5.

The four lower curves represent the exciting functions ($y$ in the diagram of model *a*), fig. 2), i.e. the profile of the

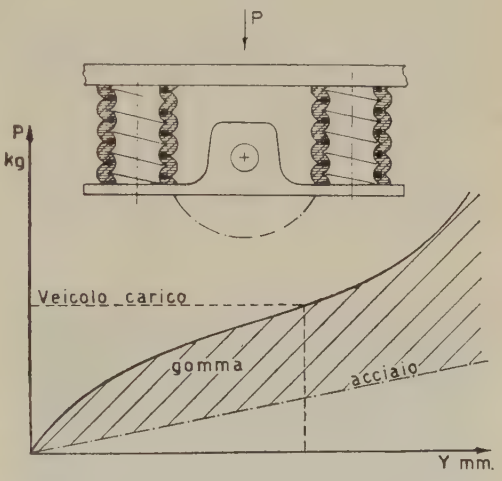



Fig. 4. — The load-deflection characteristics of the springs considered in the example of analogue computation.

N. B. — Veicolo carico = loaded vehicle. Gomma = rubber. — Acciaio = steel.

track, applied with appropriate phase displacements to the model's four points of support, i.e. the vehicle's four axles. The passage of the rail's joints under the first and second axles of the first bogie can be clearly seen from the bottom to the top of the diagram, followed after a displacement equal to the distance between the axles, by the effect under the first and second axles of the second bogie.

The upper recordings represent, on a suitable scale, the solutions provided by the computer. More specifically, these are:

— curves V and VI, the vertical accelerations $x''_1$ and $x''_2$ of the bogies, corresponding to the travel over the joints;

— curve VII, the rotational accelerations of the pitching motion of the coachwork $\theta''$, which are practically nil, and curve VIII,

its vertical accelerations X″. The curves provide evidence of the reduced amplitude and rapid damping brought about by the flexibility and viscosity of the springs;

— the curves IX and X represent the vertical displacements $x_1$ and $x_2$ of the bogies on their primary suspensions;

— the last two curves represent the pitching θ and vertical X motions of the body.

Research can, and will be, extended to more complex types of suspension with mixed rubber and pneumatic characteristics (fig. 6), designed to obtain a constant level of vehicle suspension. The complete study of these methods of suspension by mathematical methods would be impossible as they do not possess a unique characteristic, but a family of characteristics as a function of the vehicle load, whilst the use of the computer will enable the dynamic behaviour to be predicted at the planning stage.

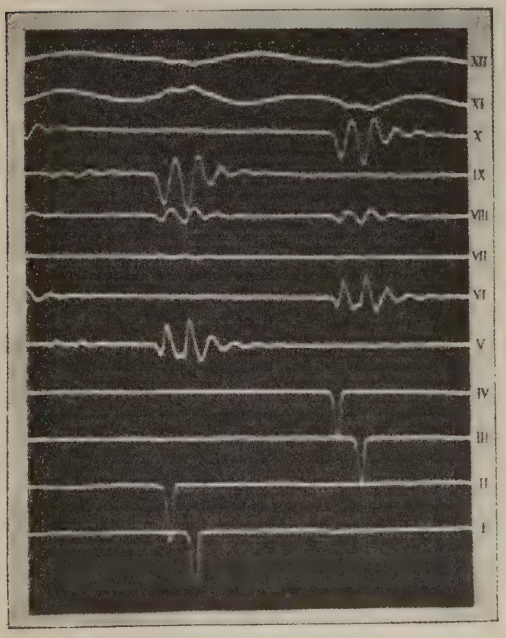



Fig. 5. — Example of recordings, at a given speed, of the exciting functions (the four lower curves) reproducing the rails and the results (the upper curves) with respect to the accelerations and movements of the various parts of the model railway carriage.

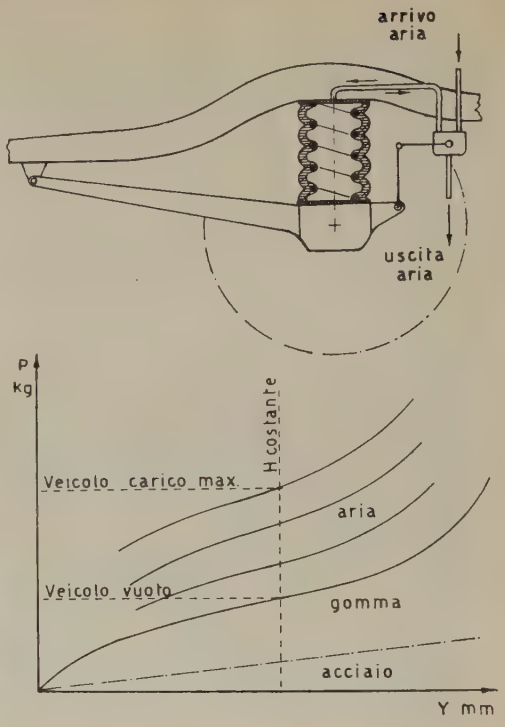



Fig. 6. — Family of load-deflection characteristics for rubber-pneumatic suspension systems.

N. B. — Véicolo carico max. = maximum vehicle load. — Véicolo vuoto = empty vehicle. — Arrivo aria = air intake. — Uscita aria = air outlet. — Constante = constant. — Aria = air. — Gomma = rubber. — Acciaio = steel.

The examples given demonstrate that one can reproduce real mechanical systems by electronic analogue computer, with a degree of accuracy enabling the elastic and viscous characteristics of springing systems and the distribution of masses to be tested and adjusted without actually having to build the vehicle being designed.

*Laboratory Section*
*of Gomma-Pirelli Co. Ltd.*
*Technical Management*
*of S. A. G. A. (Pirelli-Fiat).*

# NEW BOOKS AND PUBLICATIONS.

[ **621** .431 .72 ]

**« Die Bundesbahn », Sonderheft Diesel-Schienenfahrzeuge** (« *Die Bundesbahn* », *special issue on diesel engines on rails)* No. 23, December 1958. — A pamphlet (8 1/4 × 11 1/2 in.) of 144 pages with numerous illustrations and tables. — 1959, Darmstadt, Carl. Röhrig.

The review *Die Bundesbahn,* on the occasion of the centenary of the birth of Rudolf DIESEL, has devoted one of its issues to Diesel traction.

In his editorial Dr.-Eng. WIENS, Direktor bei der Hauptverwaltung der Deutschen Bundesbahn, gives a general picture of Diesel traction in Germany and stresses the active part and quite personal position taken by the D.B. and German industry in this field.

The review then covers all aspects of Diesel traction in a series of perfectly documentated articles from the pens of the most eminent specialists of the Deutsche Bundesbahn on the question.

The various types of stock put into service in Germany since the beginnings of Diesel traction up to the present time are briefly described.

The new policy of the D.B. since 1945 in the very delicate questions of the choice of stock and method of operating are explained and justified in a concrete fashion.

The methods of maintaining and repairing the stock, as well as the alterations and improvements made to the fixed installations are gone into at length.

The value and need for research work of all kinds on the stock (output, working of the various parts, stresses, vibrations...) and checking the lubricants used are stressed and the methods of measurements used are described.

Finally, details are given concerning the development of Diesel traction in other European countries, as well as on the private German railways.

R. S.

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[ **625** .144 .2 ]

Dr. Ing. habil. Gerhard SCHRAMM. — DER GLEISBOGEN. **Seine geometrische und bauliche Gestaltung.** *(Track on curves. Its layout and construction).* 3rd edition. — One volume (6 × 8 1/4 in.) of 302 pages with 111 figures and 20 tables. — 1958, Darmstadt, Otto Elsner Verlagsgesellschaft, Schöfferstrasse, 15. (Price : (bound) DM 20).

The geometrical layout and practical realisation of track on curves in recent years has become a matter of considerable importance owing to the real increase in the speed of the trains and ever growing demands of the public; they have therefore been the subject of a great many studies in the technical press. But a general treatise, which would answer all the problems raised by such a vast subject, was still lacking — at least in the German language. This gap was filled in 1942 by the author of this manual, which is now in its third revised and amended edition. The work is intended mainly for technicians responsible for the construction and maintenance of the permanent way; it is based essentially on the regulations of the German Railways, about which it forms an invaluable and documented commentary.

Its nine chapters deal in turn with the dynamic effects of running through curves, the superelevation and layout; the positioning of the line on the site; ordinary points and those on curves; the verification of the layout by means of versines; special features of track on curves (gauge, short rails, checkrails, transversal reinforcements, etc.) and finally the running of the vehicles on curves, their resistance to forward running and the danger of derailment (by jumping off the rail or falling over). A series of tables and diagrams complete the work, which ends with a series of public announcements which have a close relation with the subject dealt with.

The text is very clear and comprehensible, illustrated by numerous figures and carefully selected examples; it is easy to read and pragmatical in its contents. A long list of authors refers the reader to the sources of information and publications of a scientific nature.

A. J.

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[ 656 ]

**INTERNATIONAL FEDERATION OF TRANSPORT WORKERS. — Problèmes nationaux et internationaux de la politique des transports.** Le point de vue des organisations syndicales d'ouvriers des transports. *(National and international problems of transport policy. The point of view of the transport workers' trade unions).* — One volume (6 3/4 × 9 1/2 in.) of 166 pages. — 1958, Bale, Editions Pharos Hansrudolf Schwabe A.G., Totentanz, 14. (Price : bound 10.95 Swiss francs).

For many years the International Federation of Transport Workers (I.T.F.) has devoted its attention to general transport problems.

The present report which was unanimously adopted by the Amsterdam Congress of the I.T.F. in July 1958 is the basis for future efforts of the organisations affiliated to this Federation in the field of transport policy.

The first part of the report, and the most important, deals with the co-ordination of internal transport. It lays down the fundamental principles and examines the various aspects : elimination of factors causing unfair competition, making operating conditions equal, social policy, concessions, tariff policy, capital investment policy, supervision and control.

In the second part of the report, deliberately treated in a more summary manner, the I.T.F. reports the special problems with which co-ordination is faced in the case of urban, air and navigation services.

The third part of the report is devoted to the policy of transport within the framework of European integration. Limited to an examination of questions of importance at the present time, the I.T.F. enumerates the problems concerning transport economics which the signing of the Treaty on the European Economic Community has raised for the six countries concerned.

A well documented work, the I.T.F. report will attract the attention of all those who have to deal with the co-ordination of transport.

R. S.

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